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RISØ



Risø-R-1018(EN)
Risø National Laboratory,
Roskilde, Denmark
August 1998

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# Wind Energy and Atmospheric Physics Department

Peter Hauge Madsen, Per Dannemand Andersen and
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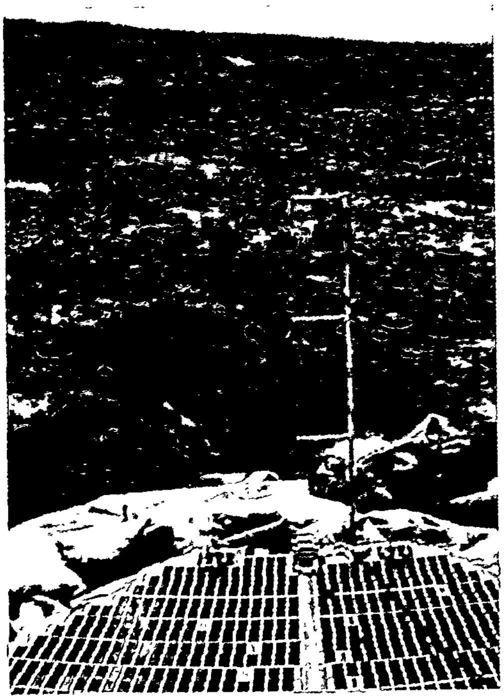

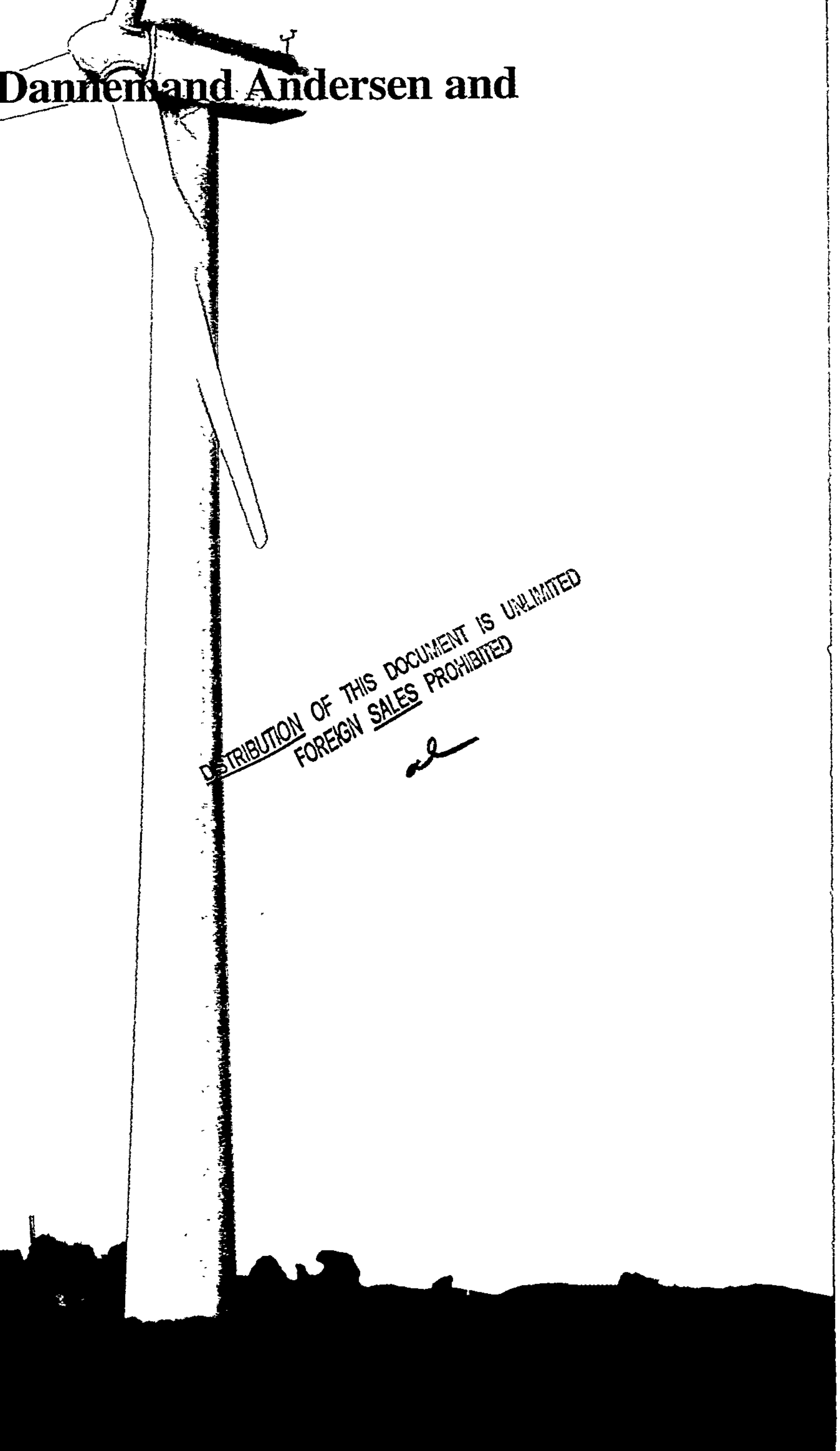



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# Annual Report 1997
# Wind Energy and Atmospheric Physics Department

**Peter Hauge Madsen, Per Dannemand Andersen and Birthe Skrumsager (eds)**

Risø National Laboratory, Roskilde
August 1998

**Abstract**
The report describes the work of the Wind Energy and Atmospheric Physics Department at Risø National Laboratory during 1997. The research of the department aims to develop new opportunities in the exploitation of wind energy and to map and alleviate atmospheric aspects of environmental problems. The expertise of the department is utilised in commercial activities such as wind turbine testing and certification, training programmes, courses and consultancy services to industry, authorities and Danish and international organisations on wind energy and atmospheric environmental impact.

A summary of the department's activities in 1997 is presented, including lists of publications, lectures, committees and staff members.

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# Contents

# 1 Introduction

The primary objective of the department's research activities is to meet the need for knowledge and consultancy assistance on wind turbine technology and the exploitation of wind power, as well as to map and alleviate atmospheric pollution. The research is carried out in collaboration with national and international universities and research organisation. The department co-operates with the wind turbine industry on wind power research and development, while the research on atmospheric pollution takes place in co-operation with the National Environmental Research Institute.

In 1997 the department employed a total of 58 academic staff, 23 technical and administrative staff and 9 Post.docs. and PhDs. From the start of the year the research has been organised in five research programmes

- Atmospheric Transport and Exchange (Søren Larsen)
- Wind Power Meteorology (Lars Landberg)
- Aeroelastic Design (Flemming Rasmussen)
- Wind Turbines (Peter Hjuler Jensen)
- Electric Design and Control (Peter Hjuler Jensen)

Furthermore the department performs the tasks

- Type-approval and Certification (Carsten Skamris)
- Test and Measurements (Troels Friis Petersen)
- Experimental Meteorology (Søren Larsen)

The key areas of expertise in the department are boundary layer meteorology, aerodynamics, aero-acoustics, and machine and construction technology exploiting full-scale field tests, laboratory tests and advanced numerical simulation.

The annual report presents the programmes and other tasks in the department including research highlights and other achievements of 1997. The reports also present the co-operation and research dissemination as well as lists of publications, lectures, committees and staff members.

Additional information on the department and its activities can be found on World-wide Web (WWW), address http://www.risoe.dk/amv/. The department's web-pages are constantly updated.

# 2 Wind Energy and Atmospheric Physics Department 1997

The Department of Wind Energy and Atmospheric Physics experienced satisfactory progress also in 1997. The department's activities were reorganised in a new structure consisting of five research programmes and three special tasks - all of them within the Risø programme area called wind energy and atmospheric processes. The purpose of this programme area is to develop methods for design, testing and siting of wind turbines, determination of wind loads and wind resources as well as methods for determination of atmospheric dispersion, chemical transformation and effects of air pollution.

This work has been performed in a close co-operation with the Danish wind turbine industry, the Danish Energy Agency, Ministry of Environment and Energy, National Environmental Research Institute, Danish Meteorological Institute, Danish Technological Institute and Norske Veritas as well as a range of Danish and foreign universities and research institutions. Mainly EU programmes under the Ministry of Environment and Energy have funded these activities.

In 1997 we have strengthened our participation in the international research and development co-operation as to wind power. In recent years our department has played an important role within organisations such as IEC (International Electrotechnical Commission, the international standardisation organisation), CENELEC (the European standardisation organisation), EUREC-Agency (the European co-operation organisation on renewable energy) and EWEA (the European wind energy association).

On behalf of the Danish Energy Agency, Risø has been a representative to the international energy agency (IEA) in the framework of the co-operation agreement on wind energy since the beginning of 1997. In this capacity we have been assigned the leading role in formulating the strategy and action plan for the IEA wind-energy activities during the next four-year period. This work is a continuation of a similar leading role in the work on strategies within EWEA and EUREC-Agency.

Also our achievement within international consultancy on wind energy has increased with tasks in India, Kazakhstan, Fiji Islands, Cook Islands, Tonga Islands, Egypt, Cape Verde, Russia and the Czech Republic.

A substantial part of our activities concerns projects under the *Wind- Turbine Programme*. The objective of this programme is to develop new understanding and methods for a) load and safety of wind turbines; b) experimental verification and c) analysis of new applications in grid-connected or in hybrid systems. The programme is responsible also for the test-station activities carried out for the Danish Energy Agency. In addition to this the department has two commercially based tasks paid by the wind-turbine industry, viz *wind-turbine testing* and *approval of wind turbines*. A great effort has been made within these fields to enhance the value of the work done for the internationally oriented wind-turbine industry.

Our accreditation work has been extended within the field of wind-turbine testing. We have been extensively involved in establishing a European network of test stations, MEASNET, to automatically ensure European recognition of testing results. Accreditation is one of the preconditions. The work to establish a new test facility for large wind turbines in Western Jutland is continuing. An important milestone is conclusion of the building activities and capacity extension of the blade-testing centre at Sparkær.

The approval activities have been increased in 1997, and among other things the positive development of this task has resulted in accreditation of DANAK as well as implementation of several German "Gutachten".

In 1997 the work on application of meteorology for wind-energy purposes was assembled in the research programme *Wind Power Meteorology*. This programme aims at contributing with new knowledge of wind climatology, atmospheric flow and turbulence as a basis for development and application of methods and models to determine wind resources and wind loads. A co-operation with EPRI, the research institute of the American utilities, was launched in 1997. The co-operation concerns implementation of models for short-term prediction of wind farm production. This work is performed in an EU-JOULE project conducted by Risø. The models applied are state-of-the-art and very exact, a result of which is the American interest in the project. Risø has applied these models since 1989 and is in the lead world-wide. The Danish utilities (ELKRAFT and ELSAM), Danish Meteorological Institute and wind farms in Great Britain and Greece also contribute to the project. As illustrated in the figure, the model has great success in its gale prediction, both with respect to size and extent but also with respect to arrival at a certain place.

The Risø programme WAS P recognised as world standard for estimation of wind resources has now been sold in a number of more than 400 copies. The largest user groups are wind-turbine manufacturers, utilities, private consultants as well as universities in more than 60 countries. The programme has been developed in a close co-operation with the Danish wind-turbine industry and the international research world and is still in progress. A WASP for Windows version will probably be available in 1998.

The research programme *Aero-elastic Design* aims at developing new knowledge of design wind conditions, properties of aerodynamics and structural dynamics, analysis models, design load basis as well as optimisation of wind turbines. In 1997 two essential results were obtained as to blade design, viz determination of the aerodynamic (static and dynamic) properties of a profile and determination of stability under stall.

In recent years advanced measuring and calculation methods have been developed at Risø to ensure prompt documentation of new blade profiles for construction of wind-turbine blades. This work was made in a project supported by the Danish Energy Agency. The measuring method has now been completed and documented. In the near future it will be applied to test a series of new profiles that has been developed at Risø and optimised especially for wind turbines. Recently measurements have been performed on the profiles FFA-W3-241, FFA-W3-301 and NACA 63-430. The dynamic calculation model has been verified in connection with EU projects. It has been compared with various models from national as well as international parties. At Risø we now have at our disposal two widely different approaches which supplement each other.

In a research project partly funded by the Danish Energy Agency and EU JOULE programme the design basis of stall regulated wind turbines has been extended in order to obtain maximum stability under stall. When in operation the aerodynamic forces of a wind-turbine blade in stall may have some components acting as negative damping. As a result energy is added to the vibrating blade which becomes potentially self-exciting or unstable. The vibration will be limited only in case the structural damping removes more energy than supplied by the aerodynamic forces. A larger stability value is obtained by increasing both the structural and aerodynamic damping in a positive way. In our research work the most important parameters influencing the damping conditions have been identified and implemented in an aero-elastic programme, Hawc. These parameters are

- static and dynamic properties of aerodynamic profiles
- structural properties of a blade
- structural and dynamic properties of the nacelle and tower.

In 1997 also the programme *Electric Design and Control* was established. The main areas of the programme are electric components for wind turbines, wind-turbine regulation, grid connection and system integration of wind turbines. A large activity of the programme has been a co-operation between Vestas, ABB and Risø with support from the Danish Energy Agency to develop a combined speed and pitch-regulated wind turbine. Risø's role has been to establish model basis for system design and analysis in preparation for optimising regulators with respect to load as well as output. In addition to this an experimental set-up with a 225-kW wind turbine and 400-kVa frequency converter has been erected. Risø has established a measuring system in order to investigate the concept. Simulation with the models developed has shown that a very good power regulation quality is obtainable. The first measurements on the site have confirmed a considerable improvement of the regulation quality. The measurements also show that improvement of the production is difficult to obtain without use of on-line optimisation.

EU JOULE has supported work within the programme on grid connection of wind turbines to weak grids. Production control from a wind farm has been established to ensure a voltage at the connection point within the limits ordered. Also a concept for wind-energy storage has been developed in order to smooth out and at the same time keep the output power from the total system (wind turbines and storage) within the voltage limits. The two concepts can contribute to an expansion of the areas with profitable wind-turbine activities since the demands on the electric grid will be reduced which again will reduce the costs of grid reinforcement.

The work on atmospheric processes takes place within a programme called *Atmospheric Transport and Exchange*. The objective of the programme is to contribute with new knowledge of atmospheric transport and transformation of airborne compounds and their exchange with man-made and natural terrestrial and aquatic ecosystems. In 1997 the work has been concentrated mainly on atmospheric dispersion, exchange between the atmosphere and surfaces and atmospheric studies. Among the results are the following. As concerns atmospheric dispersion, RODOS-2000 aims at developing an IT based decision tool for the European countries by the end of the year 2000. This is one of the demands for results to the programme in Risø's contract with the ministry. In 1997 the local-scale model system was ready. The system contains and controls all of the atmosphere programmes that are relevant in case of a nuclear accident within a distance of 40 kilometres from a nuclear power plant and it includes chains of dispersion meteorological and irradiation dose models. The Danish Emergency Management has a similar system called ARGOS-NT that is used in Denmark, the Baltic States and Poland. In 1997 Risø has worked with both systems. To a certain extent they apply the same programmes, and both systems are operational.

In a co-operation with Danish Environmental Research Institute and some international partners and supported by EU, NMR (Nordic Council of Ministers) and SNF (the National Scientific Research Council) a major issue of some projects has been air/sea exchange of $CO_2$ and other greenhouse gases. The projects aim at a better knowledge of relevant processes and improved determination of the input numerical parameters by means of numerical modelling and measuring campaigns. A result of the research is a wide development with regard to measuring technique. Deposition of N-compounds between air and sea is being investigated in a number of theoretical and experimental projects, especially focusing on the chemical and physical transformation of gases and particles in the atmosphere and the importance of their exchange with the sea surface.

In 1997 boundary-layer measurements were performed on Mars by NASA Pathfinder mission. Risø is one of the participants in the scientific group involved in interpreting the data obtained. This activity has been supported by SNF (the National Scientific Research Council).

# 3 Selected Activities

## 3.1 Computational aero-acoustics

### CAA at Risø in 1997

The process of aerodynamic sound generation on wind turbine blades is not yet fully understood. Our ongoing research aims at revealing the fundamental mechanisms involved and at finding means to control the sound generation.

Capturing all physical processes involved with the aerodynamic sound generation and propagation requires use of a method capable of predicting these phenomena from first principles. This is the topic of computational aeroacoustics (CAA), a fairly new discipline that emerged in the eighties.

The origin of CAA is computational fluid dynamics (CFD) that has matured during the past 20 years caused by advances in computer technology and numerical algorithms. Now the industry routinely uses CFD for design and research purposes.

During the past few years it has been our objective to explore the possibilities of using a recently developed CAA technique to predict the noise generated by low speed flows. The technique is an acoustic/viscous splitting technique, where the aero-acoustic computation is based on a solution of the time dependent incompressible flow equations. Thus the technique is only valid for low Mach number flows (<0.3) where the assumption of incompressibility is a good approximation. The acoustic field is the solution to a set of time dependent, inviscid, compressible equations governing the perturbations about the incompressible flow field. A separate solution of the flow field and acoustic field respectively offers the following benefits 1) numerical errors from the flow field solution do not influence the small-scale acoustic field and 2) it is possible to use different, optimised numerical schemes for each of the two fields.

In 1997 we have published a number of papers on CAA [1, 2, 3, 4]. In [2] we report the latest results using the acoustic/viscous splitting. The results concern the two-dimensional flow over a NACA0012 profile, where the angle of attack was 180. The Reynolds number based on free stream flow velocity was 1x106 and the Mach number was 0.2.

The acoustic solution shows some qualitatively promising features. Figure 1 illustrates contours of the instantaneous acoustic pressure next to a close-up of the corresponding incompressible pressure field with streamlines illustrating the flow direction. Waves form in the vicinity of the airfoil and propagate in the normal direction away from the airfoil and out of the computational domain without any noticeable reflections at the outer boundary. The wavelength is just over eight airfoil chord lengths which corresponds well to the fundamental frequency and sound speed. Furthermore the wavelength is longer downstream the airfoil and shorter upstream the airfoil because of the Doppler effect.

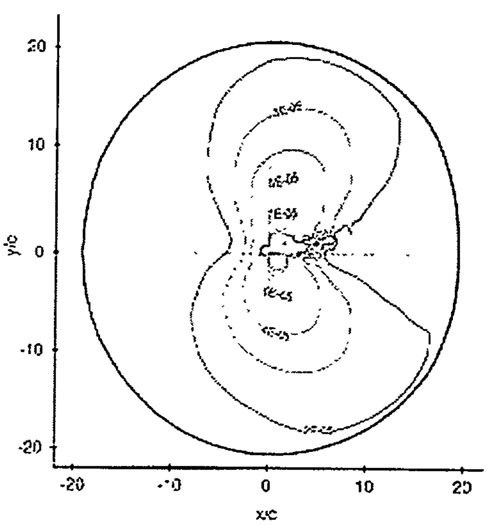



*Figure 1. Instantaneous contours of flow field pressure (with streamlines overlaid) and sound field pressure.*

Note that figure 1 shows the characteristics difference between a flow field and a sound field. The flow field is locally disturbed only by the presence of the airfoil whereas the sound field extends far away from the airfoil.

The root-mean-square pressure contours are shown in figure 2 illustrating the directivity of the sound propagation. The levels are higher in the direction normal to the airfoil above the airfoil, whereas below the airfoil the levels are higher in the direction approximately normal to the flow direction. A non-dimensional, root-mean-square acoustic pressure of 2x10-5, typically found about 15 chord lengths away from the airfoil, corresponds to a sound pressure level of 103dB (re 2x10-5 Pa) in atmospheric conditions.

The acoustic pressure amplitude falls off as (1/r)-1/2 where r is the radial distance from the airfoil in accordance with two-dimensional sound propagation theory.

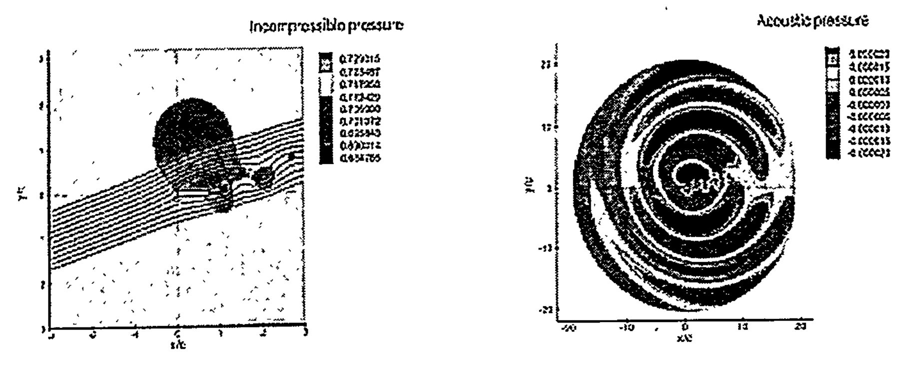


*Figure 2. Directivity pattern. Contours of root-mean-square of acoustic pressure.*

As of now it is only possible to verify qualitatively the results for real fluid flows, since they are not stable for long-term integration. So a comparison of, eg the computed pressure level to that of measured pressure is not yet possible.

## 3.2 Micro-meteorology on Mars by Pathfinder

The NASA probe Pathfinder successfully landed in Ares Vallis close to the Mars equator on 4th of July 1997. It was the first in a row of "low-cost quick discovery " missions to Mars, developed by NASA. Pathfinder was designed primarily to demonstrate the landing concept and with a continuing function for about one month, while the rover "Sojourner" was expected to function for one month only. In spite of this the mission operated for about three months after the landing. It controlled the rover tracing a trail of about 100 metres across the nearby terrain, and data were transmitted from a series of scientific and technological measuring programs. A total of 2.3 gigabits data were transmitted, including 16500 images from the lander and 500 from the rover, 16 chemical analyses, and roughly 8.5 million meteorological data. Many will remember that also the mission was something of a publicity stunt with 566 million Internet hits registered during the first month after the landing.

The data gathering was controlled at Jet Propulsion Laboratory in Pasadena, where a number of scientific groups were engaged in interpreting the incoming data and in a continuous adaptation of the data gathering strategy to the situation at the lander site as described by the incoming data. Selected by NASA and based on application these scientific groups have since then been the core groups in the ongoing data analysis. The department is part of the ASI/Met group (Atmospheric Structure Investigation/Meteorology), being responsible for the studies of the Martian atmosphere, based on the ground based measurements of pressure, temperature and velocity as well as on pressure, temperature and deceleration during descent. Most of the participating groups were American of course. The selection procedure by NASA of the few non-American groups was similar to that of the American groups except that the non-American groups had to arrange their own funding. Thus the Danish Research Council funded the Danish group. The scientific objective of our project is to evaluate the atmospheric scaling laws applied to Earth atmosphere for the Martian atmosphere. In principle these scaling laws shall apply to a wide range of planetary atmospheres, but so far the Mars data from the Viking landers have been our first chance to obtain atmospheric data from another planet. In some aspect the Viking data were less well suited for this purpose. The Pathfinder instrumentation was building partly on the experience with the Viking data and therefore better suited for our purpose.

**Atmospheric measurements by Pathfinder**

The upper air structure of the atmosphere was evaluated from the deceleration of the lander as it approached the surface. It yielded a density profile as shown in figure 3, illustrating also profiles similar to those derived from the entry of the Viking 1 lander in 1973.

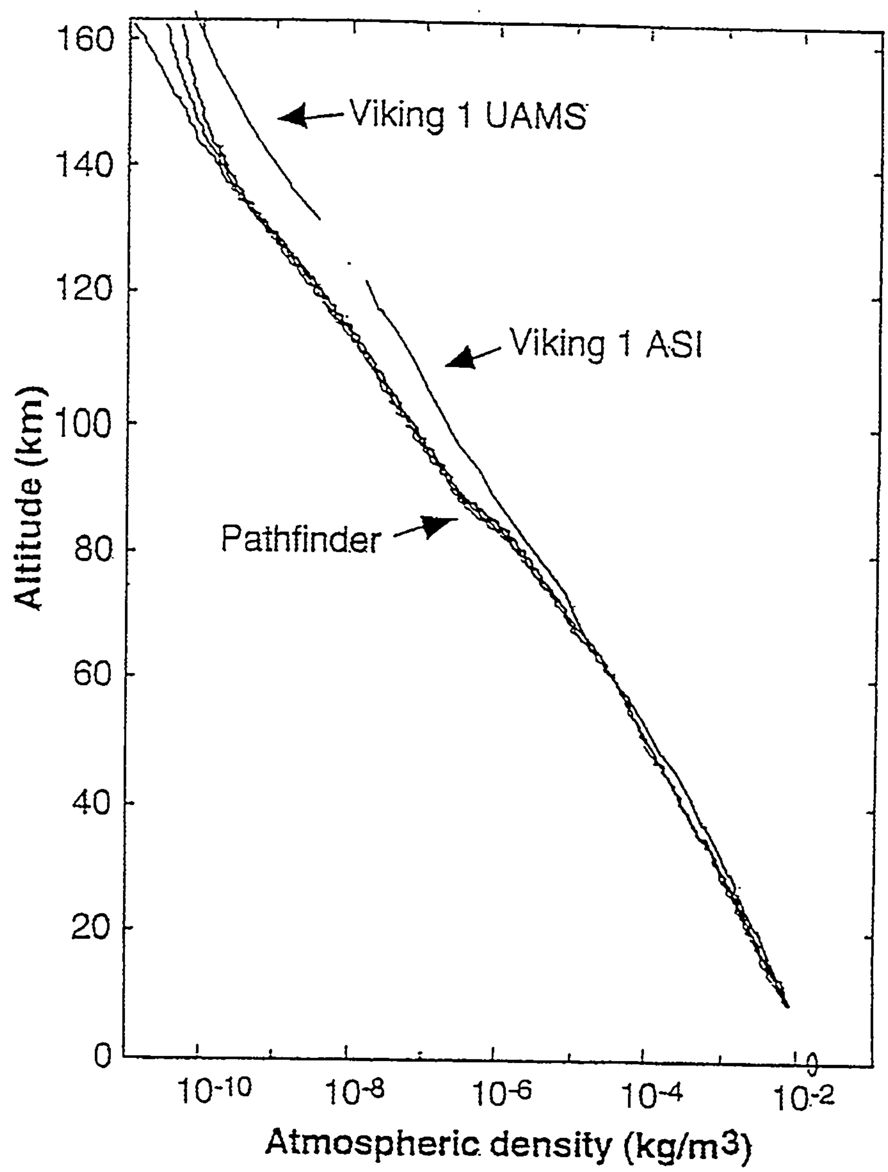



*Figure 3. Atmospheric density profile for Mars as measured during descent by Pathfinder and Viking 1 in 1972.*

After the landing the three petals around the lander opened to a horizontal level on the top of air bags protecting the lander as it hit the surface. The meteorological mast was released from its travel position to its full height of about 140 cm above the Martian surface, of which about 40-cm was constituted by the petal level above the surface. The meteorology mast is seen in its operating position on the cover page, as seen from the camera on the lander.

The meteorology mast was equipped with thermocouples measuring temperature in three heights and with six constantly current hot-wires placed in a cylindrical configuration at the top to provide wind speed and direction. The sensor response time was about one second, for which reason we could obtain not only mean values but also turbulence measurements. The sampling rate varied during the mission such that relatively slow measurements, tracking the daily variations, at times were replaced by measurements with a sampling rate of about one-second to study the turbulence structure. Metal wind sockets at three levels supported the wind measurements also. The lander camera photographed the deflection of these "sockets", indicating the wind speed and direction.

The measurements showed characteristic daily variations of temperature and pressure similar to the measurements obtained from the Viking missions. Pressure variation showed strong halfway variations reflecting tide effects. Pressure minimum was recorded 20 days after landing, corresponding to the maximum extent of the south polar $CO_2$-ice cover. Weather systems moved across the lander during the whole measuring period and could be interpreted as being dominated by baroclinic waves. The temperature variability was dominated by daily variations with a maximum of about 263 K around 1400 and a minimum around 197 K just before sunrise. The turbulence temperature fluctuations reached about 20 K in the daytime. The vertical temperature gradient also reached such values across the height of the meteorology mast. Wind speed and wind direction showed characteristic daily variations, with the wind blowing up the dominating terrain slope during the day and downwards by night, driven by the diurnal heating and cooling.

During the measurement period we were able to detect from pressure, wind and temperature signals the signature of several small dust devils passing the lander. Unfortunately we have presently not been able to find a camera picture corresponding to these events

One of our objectives was to study the relation between the turbulence structure and the mean vertical gradients. An example is shown in figure 2, illustrating our tests of the logarithmic variation of temperature with height.

All of the above supporting data have confirmed and extended the information provided by the Viking measurements and have been in accordance with our expectations for planetary atmospheres. However, so far we have as well obtained surprising data about the turbulence temperature fluctuations close to the ground, below 1 metre, where the fluctuation intensity for night time stable conditions is much reduced relative to the level expected to the normal formulations for the atmospheric surface layers. Since Viking measurements were performed at only one level, 1.6 metres, and the Viking temperature fluctuation measurements for many reasons were badly suited to study temperature fluctuations at night, this information is new and has no theoretical explanation so far. However the result has been confirmed by one of our meteorological experiments on the Earth.

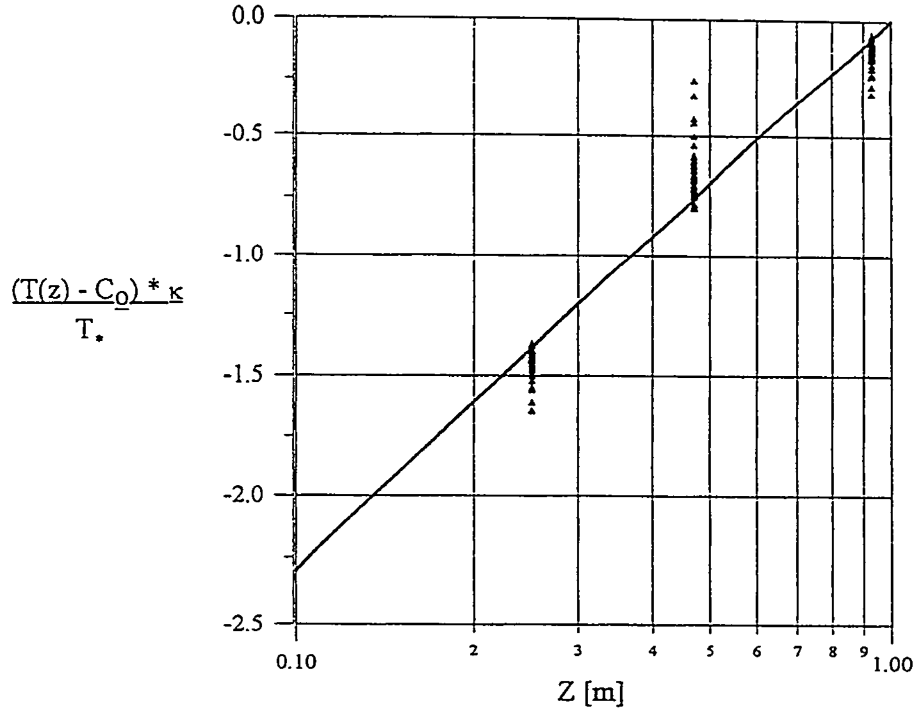



*Figure 4. Normalised vertical variation of the average temperature, T, with height, z, for a large number of Pathfinder records. The line corresponds to a logarithmic behaviour.*

**Future work**

As opposed to the temperature and pressure measurements, the velocity measurements have so far not been well understood because of calibration problems that have so far limited us to approximate estimates of the direction and qualitative estimates of the wind speed. An effort at the Jet Propulsion Laboratory is now on the way with a detailed calibration of a sister instrument to the sensor sent to Mars. Since velocity speed is a key quantity to characterise the boundary layer flow, all participants are awaiting the result of this calibration. When the result is available, one of our objectives is to correct for the flow distortion around the lander. For this purpose our plan is to apply the programs developed by our department to describe flows around bodies in boundary layers, one of which is included in the WASP program for wind resource estimation and another is the CFD-program to describe flow around wind turbine blades.

## 3.3 Sparkær Blade Test Centre

In 1983 dedicated testing of wind turbine blades began at the Test Station for Wind Turbines when a round test hall was built for this purpose. The maximum blade length for this facility was 12 metres. As a result of an increased blade size in the following years, the need for a test facility with capacity for larger blades became evident.

In 1984 a private test facility with a test rig having four mounting faces for fatigue testing of up to 20 metre long blades was built at Sparkær near Viborg. In 1986 this test centre was completed with the erection of a test hall for static tests, a material laboratory, a machine shop, a fibre glass shop and office buildings. In 1990 the RISØ blade test activity was moved from Roskilde to Sparkær, and staff was employed.

Risø tested the first 24-m blade commercially available in 1994 at Lunderskov, using Risø testing equipment. The testing was remote and controlled from the Sparkær Centre via a modem.

To meet the demand for testing of megawatt class blades a new test rig for simultaneous testing of three blades of up to a length of 45 m was planned. The new test rig was erected in 1995 when the first commercial 30-m blade emerged. For this purpose 800 tons of reinforced concrete was used. A total of more than 2500 tons of reinforced concrete is now in place for the testing systems.

Finally in 1996 Risø purchased the Sparkær Centre and a new 1250 square metre super insulated test hall heated by natural gas was erected. The new test hall represents a unique possibility for high-quality blade testing. The test facilities now at hand are described in the 1996 annual report. In 1997 considerable resources have been put into the development and implementation of the new testing facilities.

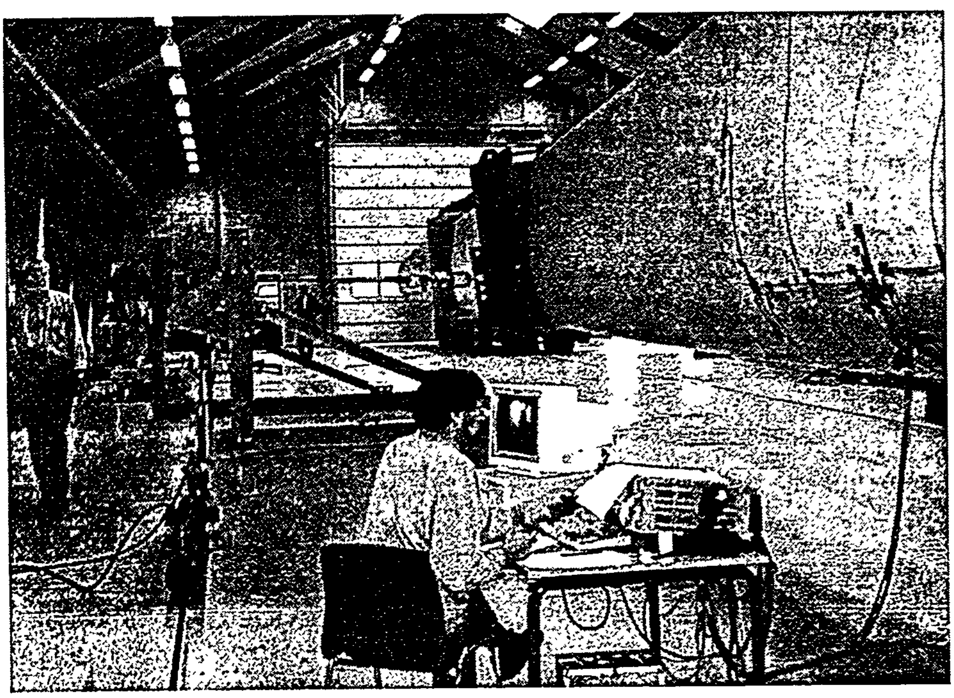


*Figure 5. Blade testing in the new test hall at Sparkær.*

**Accredited blade testing**
By the end of the year 1997 all of the commercial test work, including static, dynamic and fatigue blade tests, has been accredited by the Danish accrediting body DANAK. All measuring procedures have been scrutinised and measuring uncertainties have been described in all parts of the testing and measuring chains.

**Point loading**
The static blade testing has been enhanced by introduction of four points with simultaneous loading along the blade length. This new procedure leads to a more realistic moment and shear-stress distribution along the blade and makes it

possible to perform a two-axis static blade test in one working day even for megawatt blades.

**Implementation of a new fatigue test system**

Since 1984 full-scale fatigue testing of blades in Denmark has been based on excitation in the blade eigenfrequency. To simulate mean wind load one or more mass preloads are attached to the blade. The energy to maintain the oscillation is put into the blade by means of a gear motor equipped with an eccentric mass. The system is simple, very reliable and has low energy consumption. The primary drawback of this method is however that the mass pre-load applied brings down the eigenfrequency of the system, which again extends the test period.

It is essential for the blade manufacturer to obtain the information of the blade fatigue properties as early as possible. Therefore a new system has been developed in which an adjustable eccentric system is mounted on the floor. The preload is obtained by applying an initial force to the rod between the blade and the eccentric. The blade is excited in the eigenfrequency of the unloaded blade. To maintain a steady oscillation a flywheel is applied to the system. The new system has been used to test a small blade. Results are promising and the test period was reduced by more than 50%. A 20-m blade will be the next to benefit from the new test system.

**Low-cycle fatigue test**

Three 20-m turbine blades have been fatigue tested at a very high load level. Total blade failure was foreseen and experienced within a few hours.
These tests have given the clients valuable knowledge of fatigue damage and fracture forms at extremely high load levels. The test series were performed as part of the work to dissolve the problems of edgewise oscillations of blades on some operating turbine, experienced in the field.

**Thermal imaging**

For low-cycle fatigue and standard fatigue tests the use of thermal imaging has now been developed and adopted as a standard procedure in all fatigue tests. The technique is used to spot possible blade problem areas. This is a great help to blade designers. Thermal hot spots show energy dissipation deriving from internal friction in the blade matrix. This happens in areas with structural damping. Structural damping of an oscillation converts the mechanical energy of the oscillation into heat energy in the composite material. Thus the thermal hot spots tell about "structural damping at work" or of severe fatigue damage areas.

Provided with a stable and controlled laboratory environment and three new test rigs for megawatt turbine blades, the new test hall is a unique basis for future enhancements of our blade testing.

## 3.4 International standardisation

Risø has made a large effort for several years now with respect to international standardisation of wind turbines. The objects of this work as been:

1. to ensure wind-turbine quality by means of accepted common technical requirements;

2. to disseminate research results in a distinct and applicable form;

3. to provide a joint unambiguous technical basis for the wind-turbine trade and last not least

4. to continuously develop the technical basis for a Danish certification procedure for wind turbines.

Based on an research grant from the national energy research programme the first step in the Danish standardisation work was made in 1992 within load and safety of wind-turbine structures. This work led to the DS-472 Standard which was published in its final form in May 1992. Since 1988 the standardisation work at Risø has been oriented towards the international society. It has taken place in technical committees and working groups in the framework of IEC, CENELEC as well as the Danish National Committee of Danish Standard, S-588. In recent years the work has been supported in a contract with the Danish Energy Agency on the operation of the Test Station for Wind Turbines.

**Standardisation levels and procedures**

The work on wind-turbine standards takes place on three levels: on international level through IEC in co-operation with ISO; on European level through CENELEC and on national level through Danish Standard.

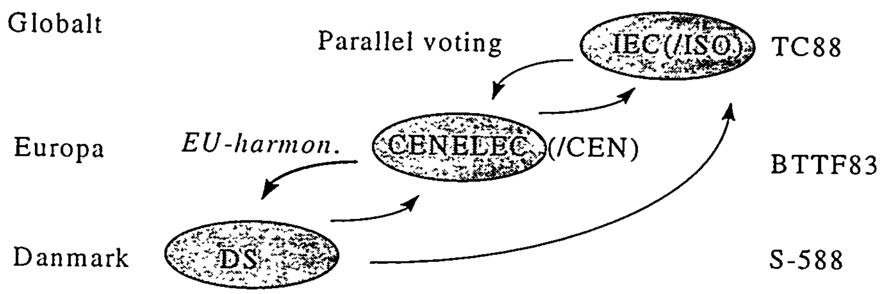
Allocation of the work and the co-operation between the three levels is laid down in various agreements and procedures the purpose of which is to make the work on the highest level possible and to avoid double work.

CENELEC will initiate new tasks only in fields with no international results or if especially requested by the EU.

With reference to the Villamoura procedure a national committee can initiate new work only in case the other European countries see no need for European standardisation work.

New standardisation work in IEC on the other hand is subject to parallel voting in CENELEC prior to possible issue as a European standard. EU harmonisation means that national standards are to be replaced by European standards when available.

Therefore the attention and effort should be directed to the global level. New standards are therefore international compromises and necessarily do not reflect Danish views and experiences in all details. However new topics for standardisation have been proposed by the national committees, and Danish influence on the technical preparation is primarily a result of the effort made.




**IEC (International Electrotechnical Committee)**
In 1987 the IEC Committee of Action decided to appoint Technical Committee no 88 "Safety of Wind Turbine Generator Systems" responsible for the preparation of standards in this field. TC88 had its first meeting in Dubrovnik in 1988, and C.J. Christensen, Denmark was elected chairman and a member from The Netherlands was elected secretary. Today the secretary is A.C. Van Giessen, FME, The Netherlands.

In 1991 the title of TC88 was replaced by Wind Turbine Systems and the objective of TC88 was replaced by "To prepare in co-operation with ISO standards for wind turbine generator systems. These standards will deal with safety, measurement techniques and test procedures."

Active member states in TC88 are the People's Republic of China, the Czech Republic, Denmark, Germany, Italy, Japan, The Netherlands, South Africa, Sweden, USA and UK.

The procedure and duration of the preparatory work in IEC on a new standard are in brief: recommendation from one or more member states or TC88 to start a working group (WG) with scope and time table for the work is put to the vote among the member states. The member states nominate participants for the working group, and their first meeting is held within a period of say six months after introduction of the recommendation.

As a rule the working group has at its disposal a period of two years to make a committee draft (CD). The draft is sent to the national committees by the TC88 secretariat for review and comments within a period of three months. The comments are put together by the TC88 secretariat and sent to the national committees or form part of the documents presented at the TC88 meeting to discuss the CD in question. This stage will last for about six months.

After this period the recommendation is sent to the vote as a CDV (Committee Draft for Voting). The time limit is at least three months, and technical comments can be sent to the working groups.

Upon approval the chairman of the TC88 will complete the recommendation and send it to the final vote as a DIS (Draft International Standard). Here the so-called six-month rule is applied. The work on a new recommendation is a long-term project that can be illustrated as follows.

***Recommendation > (30 months) > CD > (9 months) > CDV (6 months) > DIS > (9 months) > Standard***

Since 1988 IEC TC88 has set up 11 working groups, cf the table below. It has recently been suggested by the Danish National Committee to prepare an international standard on lightning protection of wind turbines. Background material already exists in the form of Danish ongoing work as well as IEA work. At the next TC88 meeting in March 1998 a decision will be made on the subject. Denmark is willing to present a convenor as well as a technical expert from Elsam Project and DEFU respectively.

| WG | Task | Con | Status | Standard |
|---|---|---|---|---|
| | International Electrotechnical Vocabulary - Chapter 415: Wind turbine systems | | CDV 1995-11 | |
| 1 | Wind Turbine Generator Systems - Safety Philosophy | IT | 1. ed. 1994-12 | IEC 1400-1<br>ENV 61400-1 |
| 2 | Wind Turbine Generator Systems - Engineering integrity | DK | 1. ed. 1994-12 | IEC 1400-1<br>ENV 61400-1 |
| 3 | Wind Turbine Generator Systems - Installation, maintenance and operation | US | 1. ed. 1994-12 | IEC 1400-1<br>ENV 61400-1 |
| 4 | Wind Turbine Generator Systems - Safety of small wind turbines | EN | 1 ed. 1996-04 | IEC 1400-2<br>EN 61400-2 |
| 5 | Wind Turbine Generator Systems - Acoustic Noise Measurement techniques | US | CDV 1995-01 | IS mid 1998 |
| 6 | Wind Turbine Generator Systems - Power performance measurement techniques | DK | CDV | DIS ult.1997 |
| 8 | Wind Turbine Generator Systems - Testing Methods for rotor blades (Guideline) | NE | CD 1997-10 | IS ult. 1998 |
| 9 | Wind Turbine Generator Systems - Certification procedures of wind turbines | DK | CD 1998-02 | DIS mid 2000 |
| 10 | Power Quality Requirements for Grid Connected Wind Turbines | DK | CD 1998-02 | IS mid 2000 |
| 11 | Mechanical Load Measurements | NE | CD 1998-02 | IS mid 2000 |

It will appear from the above that IEA-C has already prepared two wind-turbine standards. The IEC 1400-1 standard addresses the size of wind turbines manufactured in Denmark, and it was not approved as a proper European standard, and thereby nor as a Danish standard.

In a European context the first edition of IEC 1400-1 is a preliminary standard (ENV). This is owing to various reservations including one by the Danish part. Instead a revision was started by WG7 at the time of the voting.

## CENELEC

The European Commission has entrusted CENELEC and its sister organisation CEN with the task to prepare harmonisation standards in relation to the various directives. In 1995 CENELEC (the European standardisation institution for electricity and European counterpart to IEC) was authorised by the European Commission to prepare wind-turbine standards to cover the demands of the actual directives and particular European needs if any. For this task CENELECX has appointed BTTF 83-2 (Technical Board Task Force 83-2 with C.J. Christensen from Denmark as chairman and with D. Bakker, the Netherlands as secretary.

BTTF 83-2 has set up five working groups. At present WG5 is awaiting a decision on further work in the framework of IEC before starting a major activity. The five working groups are:

WG1 - Engineering Integrity (Chairman: P. Simpson, UK)
WG2 - Electrotechnical Issues (Chairman: P. Gardner, UK)
WG3 - Labour Safety (Chairman: Ramakers, NL)
WG4 - Acoustic Noise Measurements (Chairman: Klug, DE)
WG5 - Power Performance of WTGS in complex terrain.

A starting point is that BTTF 83-2 will not work in fields attended by TC88 in IEC except in case of particular European needs or demands. It is the intention in the first place to incorporate the European demands and viewpoints in the IEC standards. The first three working groups have made a proposal to incorporate the European demands of a directive in the IEA 1400-1 "Safety of Wind Turbine Systems". Most of these demands were accepted at the latest TC88 meeting in October 1996 in Japan. Danish participants are J. Lemming, P. Hjuler Jensen and P. Hauge Madsen, as occasion requires.

**Danish Standard**
In Danish Standard the Danish National Committee is called S-588. Chairman is Peter Hauge Madsen. Most parties in the wind-turbine field are represented though Risø members dominate the committee. The tasks of the committee are to make proposals for the Danish vote, prepare Danish comments, suggest participants to TC88 and BTTF 83-2 meetings as well as to working groups. The committee follows the current work in the working group and arranges seminars and discussions with industry when needed. The committee has not dealt with independent Danish standards though wind-turbine standard DS 472 now needs a re-evaluation or perhaps a readjustment after the first five-year period. DS 472 is based on the construction standards and after readjustment of the latter, the need for a re-evaluation of DS 472 is increasing. When IEC 1400-1 has come out as a European standard, Denmark is to withdraw DS 472 within a period of one year (max. five years). Additional requirements in Denmark must be based on a special legislation. As a rule the committee is called together four times a year.

# 4 Programme Results

In the following selected results from 1997 are briefly presented.

## 4.1 Atmospheric transport and exchange

The objective of the programme is to contribute with new knowledge of atmospheric transport and transformation of airborne compounds, their exchange with man-made and natural terrestrial and aquatic ecosystems with regard to environmental investigations, emergency tasks and environmental recommendations on production processes.

The ATU activities can be divided into three broad categories: *atmospheric dispersion; exchange between the atmosphere and different ecosystems; basic atmospheric studies*. Activities within these categories are summarised below.

**Atmospheric dispersion**

The RODOS-2000 project aims to establish a comprehensive and operational decision support system (DSS) for emergency management support in connection with nuclear (and industrial) accidental releases affecting the European Community. The project, supported by the EU Radiation Protection Research Program DGXII, involves institutes and laboratories from eight EU member states in addition to 12 associated institutes within Central and Eastern Europe. In 1997 VEA/ATU conceived the decision support system's local -scale atmospheric model chain (LSMC). This module provides real-time atmospheric dispersion, deposition and dose estimates and forecasting in the vicinity of the source location out to 40 km in all directions. The LSMC was designed to incorporate on-line real-time met-data from meteorological stations and from on-line accessible high-resolution numerical weather forecast models. The new module consists of pre-processing software integrated with local-scale flow and turbulence models that provide wind and scaling parameters to calculate dispersion, deposition and gamma radiation dose rates on a 1x1 km grid by the Risø RIMPUFF dispersion model.

A similar, although more narrowly focused, system denoted ARGOS-NT is applied by Danish Emergency Management Agency and used in the Baltic countries and Poland as well. Our department works with both systems that to some extent apply the same atmospheric models.

The department participated in the ACE-2 project financed by EC that was concluded by the end of 1997. The objective of this project was to monitor and understand the air chemistry, especially with respect to aerosols, of European air masses moving across the Atlantic. Part of the project has focused on monitoring the cloud transformation processes as the air mass was forced above the mountain ridge of Tenerife. The Risø group has been involved in understanding and characterising the flow aspects, as the air moved across the ridge with terrain grades of up to 3:2. From one year of project data it has been possible to develop a description of the individual flow types across the ridge, their characteristics and their frequency.

The coefficient determining the rate of relative diffusion for inertial range turbulence is not very consistently determined in literature despite that the coefficient is integrated into many dispersion formulas used in air and water. The coefficient is now being carefully measured in a laboratory experiment conducted in the department in co-operation with the department of System Analysis. The Danish Research Council finances the project. The relative dispersion of fine glass particles suspended in water and moved by isotropic grid turbulence is measured to a few hundredth of millimetre accuracy, using a photographic technique.

The meteorology data from the Risø meteorology towers are now used to drive an on-line dispersion model of continuous release from Risø, modelled by the Risø puff model, enabling us to trace the dispersion of a release starting at an arbitrary time. The resulting dispersion pattern can be found through the Web site of the department.

The department was responsible for several workshops arranged to update and clarify the state of atmospheric research related to dispersion: the 22$^{nd}$ NATO/CCMS ITM Conference on Air Pollution Modelling and its Applications was held in Clermont-Ferrand, France with 152 participants. A workshop was organised at Risø within the framework of EUROSAP on the determination of the height of the atmospheric boundary layer. The workshop had 67 participants. Another workshop on the Stochastic Behaviour of Smoke Plumes, supported by the Danish Strategic Environmental Research Program was held at Risø with 30 participants..

**Exchange between the atmosphere and different ecosystems**
Many of the activities within this category have taken place in a co-operation between national and European parties, where especially EC has had a strong presence.

The staff of the Atmospheric Exchange and Transport Program (ATU) participates in the EUROFLUX project funded by EU. The project aims to make long-term measurements of the fluxes of water vapour, sensible heat and $CO_2$ between different (approximately 15) European forest types and the atmosphere. By the end of 1997 we have been able to conduct these flux measurements successfully for 15 months on a nearby site at Sorø, Zealand, where eddy correlation was applied over a beech forest. The project is continuing.

A similar project (EC-BEMA) aims to map the bio-emissions from different types of vegetation in the Mediterranean region. In 1997 the measurements took place in Spain, focusing on the VOC emissions from an orange grove. During these measurements the relaxed eddy accumulation method was applied successfully for a number of species for which the concentration can presently not be measured with sufficient high frequency resolution for eddy-correlation measurements.

A third project (EC-GEFOS) on surface exchange deals with natural emissions of $N_2O$ (laughing gas), $CO_2$ and $CH_4$ (methane) from farmed organic soils. These gases are all greenhouse gases. Fluxes were measured by traditional chamber techniques as well as micro-meteorological techniques (relaxed eddy accumulation) in co-operation with IVL, Gothenburg, Sweden.

Most micro-meteorological formulas relating fluxes and mean profiles presuppose horizontal homogeneity. Therefore it is important to device methods to relate this idealised basic assumption to the horizontal inhomogeneous conditions prevailing in the real world, such that the micro-meteorological results can be usefully applied here. Presently several methods are being applied and tested within ATU projects.

In the NOPEX project, funded by the Nordic Council, area averaged fluxes of sensible and latent heat are being measured at several locations in a mixed boreal landscape for comparison with different area flux integration schemes. One of the practical schemes showing good success is based on reversion of the formulas for growth of the planetary boundary layer as a function of the surface heat flux. The boundary layer model used was validated as well using an extensive data set from greater Vancouver. A different approach is being developed within a number of European projects, EC and EUROTRAC, as well as within the Danish DANMAC project. Here existing models for step change of the surface roughness are being modified also for scalars. To obtain the detailed surface information necessary for application of these models, the projects focus on the use of remote sensing, especially satellite data, as being the only possible source for the necessary amount of data.

Air-sea exchange is a key discipline within a number of environmental projects aimed mostly at global change issues or at the eutrophication of regional seas.

As the sea is the final depository of $CO_2$ and the source/sink of unknown strength for many greenhouse gases, a number of EC projects have focused on the air-sea exchange processes for these species. The work has taken place both in the form of laboratory studies (Luminy) in the wind water tunnel in Marseilles and as field measurements (ASGAMAGE) at the Dutch platform Meetpost Nordweijk. However the ATU program is involved also in projects that aim to map the exchanges for a whole oceanic region, OMEXI and OMEXII that focus on the carbon balance for the European marginal seas. The measuring part of these projects have mostly been a combination of flux estimation by micro-meteorological and equilibrator partial pressure methods. The work has focused on modelling the turbulence diffusion and the chemical transformation in the water phase.

A problem of more regional nature than the above global ones is the eutrophication of regional seas, where the importance of the atmospheric pathway is now well established. (30-50% of the annual load of nitrogen to regional seas come through the air) A number of EC and NMR (Nordic Council of Ministers) projects therefore aim both to refine the air-sea exchange models for a number N-species (aerosols, $NH_3$ and $HNO_3$), and also to map the total deposition and seasonal occurrence for specific marine areas.

**Basic atmospheric studies**

Risø's mobile LIDAR system has been improved both with respect to sensitivity and reliability. It can now be used for continuous monitoring of the aerosol back scattering structure in the lowest few kilometres of the atmosphere. The height and growth of the mixed layer can often be inferred from the measurements. The system has been successfully validated using measurements from the 120-meter meteorology tower at Risø. The system is aimed at future field experiments and will be further improved and developed.

Risø participated in a boundary layer experiment at Sodankylä in Finnish Lapland to study the structure of the boundary layer in sub-polar winter climate. A striking result was the influence on the boundary layer by heat flux originating not from the land covered with snow but from the part of the trees without snow cover.

ATU participates in the NASA Pathfinder mission to Mars, where our role has been to interpret the meteorology data from the mission; preliminary results are presented in a feature article in the present report.

The non-local influence on the humidity and temperature fluctuations in the atmospheric surface layer has been investigated based on experimental data. The data used are from the marine atmospheric boundary layer in the middle of Kattegat (the Ocean90-Anholt campaigns) and from the campaigns at the Vindeby offshore wind-turbine site during the ONR RASEX experiment. An empirical model relating the $q$-$T$ correlation to the intensity of the surface fluxes and features of the boundary layer height has been developed.

When modelling atmospheric transport of reactive substances, an unresolved problem has been to what extent the diffusion coefficient used for closure should be modified because the transported material changed concentrations not only owing to diffusion but also owing to chemical reactions. From studies based on both theory and data on Radon220 reported in literature we have found, somewhat surprisingly, that for first- order reactions, the so-called Damköhler correction was negligible. Similar results have been found for the diffusion of different species of the carbon budget in the oceanic surface layers.

## 4.2 Wind power meteorology

The objective of the programme is to contribute with new knowledge of wind climatology, atmospheric flow and turbulence as a basis for development and application of methods and models to assess wind resources as well as wind actions on wind turbines and buildings in all sorts of natural terrain.

**Short-term prediction**

1997 saw the first full year of on-line predictions of the power output from wind farms. This was part of a project funded by the EU JOULE program. The on-line predictions were made available to the utilities via the Internet as WWW-pages. The on-line system made predictions for wind farms in Denmark (the ELKRAFT and the ELSAM areas), UK, and Greece. Preliminary analysis showed that the predictions were quite accurate in predicting storm events.

A parallel track in the project was the implementation of the prediction model in the USA. In co-operation with EPRI the model was tailored to US conditions first to a site in Texas, which was abandoned, and then to a site in Minnesota.

The last track in the project was the development of a model combining the virtues of physical and statistical model. This work was initiated and a PhD-student is now working on the model development.

The project has met a lot of interest nationally as well as internationally. In 1998 the project will be extended to a number of wind farms in Germany, this project will almost certainly also receive funding from the European Commission.

**Wind Atlas for the Kola Peninsula**

As part of a feasibility study to introduce wind energy in the Kola Peninsula, a wind atlas has been prepared. Kola is situated in Northwest Russia, close to the Finnish border. The study has been performed as a co-operation project under the EU Non-Nuclear "JOULE" energy programme with participation of Finnish, Danish, German, Greek and Russian researchers. The wind atlas was based on wind measurements from 12 meteorological stations over about 10 years, and for each of the stations it contains the wind statistics as transformed to a number of standardised terrain types. Good wind resources were found along the coastline, especially along the northern coast, and to a less extent also in the valley region north and south of Murmansk. In contrast, the inland of the Peninsula has low wind.

The project involved investigations of establishing wind turbines at smaller communities - kolkhozes in the Murmansk area as well as at isolated settlements on the south coast of the peninsula - and it also included visits to such communities. Also the possibilities for establishment of large wind farms, directly connected to the electrical grid, have been investigated. Frustratingly, settlements with the highest wind potential - close to the north coast - are still restricted areas, which in practice prevents introduction of modern (western) wind energy technology to these communities in the near future.

The project was concluded by a presentation of its findings to the Russian regional administration and to the public. This took place at a meeting in the in the town hall of Murmansk in December 1997. As presented by the project group, the prospects for use of wind energy in Kola were generally found to be good, but mainly two problems of institutional nature had to be solved as also recognised by the Russian administration. These problems regard the need of communities to be financially credible in order to obtain western financing of wind energy projects. This regards also the low Russian electricity tariffs, which for the moment prevent the environmental benefits of wind energy to be appreciated.

Hopefully the near-future outcome of the project will be the establishment of one or more wind turbine demonstration projects at kolkhozes or settlements. Especially for remote settlements this will mean a release from a strong dependence on oil energy supply, and it will have perspectives for a much larger number of isolated communities in northern regions of Russia.

**WASP - 10 years in the international market place**

The Wind Atlas Analysis and Application Program (WASP) was introduced by the department ten years ago, in the summer of 1987. This PC program package is used to analyse wind data, model the influence of the terrain on the wind flow. It is used also to generate wind atlas data from measured data, and to estimate the wind climate and wind resources of specific sites including the calculation of the expected power production from a given wind turbine or wind farm.

Today, the program is considered widely as the *de-facto* standard with respect to wind resource estimation and as a tool for optimum siting of single wind turbines and wind farms. Over the years, the program has been applied by more than 400 institutions and companies in well over 60 countries around the world. Engineering consultants, universities and research institutions are typical users, but also meteorological services, utilities, wind turbine manufacturers and international organisations use the program.

A wind farm efficiency program has always been included in the WASP package. In addition, the department has also developed and marketed the WASP Utility Programs and a 32-bit version of WASP; Windows versions of these programs are now in the making. Furthermore a number of more general tools for wind climate and turbulence estimation are being developed and tested; the aim being to develop a more complete engineering tool that can be applied in a wide range of construction tasks in the atmospheric boundary layer.

There has been a long-standing, unsettled discussion whether the wind climate is essentially the same all over the country or whether it is true, as folklore has it, that there is a higher frequency of strong storms in the western parts. This question is of importance for extreme-wind assessment in the Danish Code (DS 410). Also, when estimating the future wind-energy production by particular wind-turbine installation, data from weather stations elsewhere are often used under the assumption that the wind speed statistics over a limited area like Denmark is a function only of the height and terrain characteristics. This is the same as stating that the external wind forcing, i.e. the geostrophic wind velocity, is statistically the same all over the kingdom.

To test this hypothesis, a network of six barometer stations has been established. There are four stations in Jutland: Ulborg (west), Kegnæs (south), Grenå (east) and Hjørring (north), one station at Risø and one at Gedser, the southernmost point of Denmark. With the pressure differences in any station triangle one can calculate the magnitude and direction of the average geostrophic wind velocity in that triangle. In principle it is possible to analyse a total of 24 different triangles, albeit not all of them are equally useful for studying the geographical variation of the geostrophic wind.

Furthermore it is possible by means of four barometer stations to follow low-pressure trajectories. The necessary software has been developed and tested on a limited set older data from barometers of limited quality. Good agreement was obtained between surface-layer wind speeds derived from these pressure data and simultaneous records from anemometers.

The new barometers are accurate within 0.05 HPA and specially designed pressure ports secure minimal disturbance from interaction with the local wind.

The measurements will start in the beginning of 1998. It should be possible after one year to answer some questions about the climatology of the geostrophic wind, in particular if it is not geographically uniform over Denmark.

**Model for offshore roughness lengths**

The offshore roughness length $z_0$ is considerably smaller than is found on land, leading to increased wind speeds and decreased turbulence levels. In contrast to the $z_0$ on land, which usually can be considered constant, the offshore $z_0$ varies with varying wave field leading to dependencies on a number of factors:

- wind speed
- upstream distance to nearest land
- water depth.

Traditionally the offshore $z_0$ has been modelled in a simple way by using a value representative for some average wind speed, ie in WASP a value of 0.2 mm is being used.

The conventional way of improving the model has been to use the so-called Charnock relation resulting in a variation proportional to the wind speed raised to a power of the order of two. This relation seems to work fine far away from any coast lines, but moving closer to the coast it becomes necessary to adjust the constant of proportionality to a higher value, which previously has been done in a quite arbitrary manner since good models have not been available.

Growing water waves take energy out of the wind to feed their growth, efficiently at first, then at a decreasing rate as the waves grow and get older, leading to high $z_0$ for 'young' waves and much lower $z_0$ 'old' waves.

In a co-operative project with Danish Hydraulic Institute we have used wave data from the RASEX and other experiments together with a model that enabled us to calculate $z_0$ from knowledge of the wave structure. This resulted in a model for the variation of the Charnock constant as a function of wave age, which in turn could be related to the upstream distance to a coast. The model was successfully verified against measurements from coastal and offshore sites providing a much better description of the data than a simple Charnock model.

**Calculations of offshore wind resources**

Existing models for the estimation of offshore wind resources are based on the models used on land with minor modifications because of known differences in the variation of atmospheric stability offshore. They roughly replace the daily cycle seen over land by a seasonal cycle mainly caused by the much higher heat capacity of water compared with a land surface. There have been very few possibilities to calibrate these models against real data because of the scarcity of offshore data. As a result of the large interest in Danish offshore wind farm installation, a number of sites in the ELKRAFT area have been subject to instrumentation. The initial data from these sites have been analysed together with data from near-coastal and coastal stations.

Preliminary results show that when applying a coastal station to predict an offshore location using WASP, the results were generally good with slight overestimation of WASP in the intermediate near-coastal range 1-3 kilometres from land. Making the predictions with use of a standard wind climate, giving good results over land, the WASP method leads to consistently low results. They vary with upstream fetch but average a deviation of about 10 % on a yearly energy prediction when compared with on-site measurements. The reasons for this behaviour are still being investigated and will be further pursued as more data become available.

## 4.3 Wind turbines

The "Wind Turbine Programme" is used to develop knowledge and methods for assessment of load and safety for wind turbines, experimental verification and technical and economic analysis of the application and feasibility of wind turbines for power systems as well as for hybrid power systems. The aim is to contribute to a reliable basis for development and utilisation of wind-turbine technology and to support the goals of energy policy in order to promote the application of Danish wind power technology.

An increasing part of future wind turbines will be erected in wind farms owing to the diverted reduction in grid costs, the limited number of sites with optimal wind potential as well as environmental requirements. Therefore prediction of the wind-induced loads in wind farms is of vital importance.

Measurements have revealed an increased loading of wind turbines in wind farm configurations compared to stand alone turbines, other things being equal. The increase in fatigue consumption in wind farms originates both from modified mean wind field and modified turbulence field.

Within the JOULE-project EWTS II, a simple semi-empirical model has been developed that model the wind field in the shade of an upstream turbine. The procedure is verified for wind-turbine spacing larger than three rotor diameters, and it takes advantage of the traditional parametrisation of the wind field. Consequently it is directly applicable with existing aero-elastic codes for the evaluation of loads on relevant components.

The procedure is accepted by the major certifying body, Germanischer Lloyd, as part of the basis for certification of wind turbines.

**Power performance assessment**

The project aims to improve existing methods to assess the production capability of wind power plants. The decision to start the project was based on unacceptably high uncertainties in present-day assessment methods, 5-10% in flat terrain and 10-15% in hilly or mountainous terrain.

In the project both experimental and analytical methods are investigated. Considerable amounts of data as well as computational tools are available. The work so far has led to identification of the main components of experimental performance assessment:

- site calibration: derivation of flow characteristics at the position of the wind turbine from measurements in the close-by meteorological tower

- sensitivity analysis: determination of the wind-turbine sensitivity to different flow parameters by means of multivariate regression analysis

- blockage/wake: the effect that the presence of the wind turbine/wind farm influences the flow at the met tower position. This means that the reference measurements are not made in the "free" flow.

Also alternative methods such as the application of nacelle anemometry are being considered. It is proposed that the basis for future warranty measures should be a reference power curve: power output as a function of not only wind speed but also other relevant parameters such as turbulence, air density shear etc. Thus the result of the performance assessment of a wind power plant is abstracted to be a set of reference power curves, $P_i$, for the individual wind turbines in the plant. From this the average reference output of the plant can be calculated and used as a warranty measure. Also the uncertainty shall be assessed in details.

## Isolated systems

The project aims at identifying needs for and bottlenecks of application of wind energy in isolated power supply systems and to propose methods to facilitate future implementation schemes. The background is poor results so far in terms of quantity as to use of wind power in isolated systems.

As a result a review of work done in the field has been conducted which shows a definite want for the project. Measurements and data collection in Egypt have been initiated. Results from this activity will be used to verify methods developed as part of the project.

**Isolated power supply systems with wind power**

Presently studies of isolated systems have been case-oriented, and because of the strong individuality of systems with few components it has been difficult to extend results from one project to another. Thus the objective of this project is to develop more generally applicable assessment and design criteria for isolated power supply systems. The expected result is a set of guidelines for design of such systems.

The main project components are:

- review of relevant studies of isolated systems (in progress)
- analysis and specifications of user requirements to the system
- development of methods
- design tools

- data collection and measurements in Egypt (also in progress) and verification of models
- reporting.

Participants:
- Risø National Laboratory
- Darup Associates Ltd.
- New and Renewable Energy Agency (NREA), Egypt

## 4.4 Aero-elastic design

The objective of the programme is to develop new knowledge of design aerodynamics and structural dynamics relevant for wind turbines and aimed at new wind turbine concepts and calculation methods for analysis, load basis, design and optimisation of wind turbines.

**Airfoil design method**
A method has been developed for design of airfoils to wind turbines. A numerical optimisation algorithm was combined with XFOIL, which is a commercial state-of-the-art airfoil flow solver. The method allows optimisation of the airfoil shape with respect to multiple objectives including aerodynamic and structural properties. To include off-design, aerodynamic properties at different angles of attack are taken into account.

An airfoil family was designed and tailored for use on a 600-kW wind turbine. Special attention was given to insensitivity to leading edge roughness for the airfoil maximum lift and to good aerodynamic performance at high relative thickness. The project was carried out under contract with the Danish Energy Agency.

**Determination of airfoil characteristics**
Minimum uncertainty on the aerodynamic characteristics of applied airfoils is very important to the design of new wind turbine blades. The stationary as well as dynamic properties should be well documented. Advanced measurement and calculation methods complement each other. Calculations are fast and inexpensive, but nut fully sufficient for industrial acceptance. Measurements on the other hand have high industrial acceptance but are expensive and time consuming.

The measurement method was recently used on the FFA-W3-241; FFA-W3-301 and NACA 63-430 airfoils that are used on the inboard part of Danish wind turbine blades. In the near future new airfoils developed at Risø for application on wind turbine blades will be tested. The Navier-Stokes calculation methods were verified on the DU-91-W2-250, RISØ-1 and NACA 63-215 airfoils. The project was carried out under contract with the Danish Energy Agency and with the European Commission.

**3D rotor computations**
A series of rotor predictions using the EllipSys3D Navier-Stokes solver has been performed in 1997. Till now these rotor predictions are the most advanced rotor calculations performed in Denmark. In contrast to earlier investigations, the full rotor trailing vortex sheets are included in the computations. The power production computed is in good agreement with measurements with a maximum deviation of 10% for wind speeds between 7 and 18 m/s. In addition detailed

information is available on pressure distributions, separation lines etc. from these computations.

**Aero-elastic design**
This design aims at maximising the stability margin during stall. The research objective is to improve the design basis for stall-regulated wind turbines, specifically aiming at maximising the stability margin during stalled operation. During stall a wind turbine blade might experience aerodynamic force components, which act as negative damping forces and supply energy to a vibrating blade, resulting in a potentially self-exciting or unstable structural system. Only if structural damping removes more energy than supplied by the aerodynamic force, the vibration will be limited.

This means that improvement of the stability conditions can be achieved both by increasing the structural and the aerodynamic damping in respect of more positive values.

The research has identified the main parameters, which influence the aerodynamic damping. The aero-elastic code Hawc has been extended to include the effect of these parameters. The most important parameters are

- static and unsteady airfoil data
- structural and dynamic properties of the blade, in particular the local direction of vibration is important
- structural and dynamic properties of the nacelle and the tower, in particular the second yaw and tilt modes are important.

The importance of these parameters has been verified by comparing aero-elastic calculations and measurements. The results show that aero-elastic calculations can be effectively used as a guide for choice of design parameters, the net result being an improved stability margin. The design procedure makes it possible to avoid instability within the operational wind speed range.

The research has been funded in part by The Danish Ministry of Energy and the EC JOULE programme. The Danish manufacturers Bonus Energy A/S, LM Glasfiber A/S, NEG Micon A/S and the Technical University of Denmark have participated in the research.

**Double stall**
Power measurements on stall-regulated wind turbines occasionally have shown two distinct maximum power levels. The phenomenon, called double stall, is undesirable for several reasons. The difference in maximum power and blade loads, respectively, can be up to 25%. This causes uncertainty in the estimate of the annual production and in the maximum loads. Furthermore it seems that double stall can influence the sensitivity to stall induced vibrations.

Double stall has been investigated by analysing the flow around airfoil sections in stall based on detailed flow computations (CFD) and measurements on full-scale rotors and in wind tunnels. The computations reveal that the phenomenon is associated with the existence of a laminar separation bubble at the leading edge of the blade and controlled by the stability of the bubble. Measurements and computations show that double stall can be avoided taking account of this condition during airfoil design. The investigation was partly financed by the Danish Energy Agency.

## 4.5 Electric design and control

The objective of the programme is to obtain new knowledge and models to analyse and develop new methods and principles for control, electric machines and power electronics. To develop also new design models for the electric integration of wind turbines in centralised and decentralised power systems. This work is done to prepare more efficient energy concepts and improved energy output and capacity ratios.

**Combined variable pitch and variable speed control of wind turbines**

The typical Danish wind turbine has an induction generator directly connected to the grid. This is a very simple and robust solution. It does however have some drawbacks. The two main drawbacks are the rather stiff connection to the grid and the second is the requirement of reactive power to be supplied by the grid. One of effects of the stiff connection to the grid is that the power is not controlled very well resulting in power fluctuations that can cause flicker and requires a larger drive train. The reactive power consumption gives rise to increased losses in the grid. One way to overcome these limitations is to combine the standard induction generator with a frequency converter. A frequency converter converts the fixed frequency of the grid to a variable frequency on the generator. Also it makes it possible to connect the generator to the grid without disturbances and to supply the generator with reactive power and supply only active power to the grid. The advantages of having a variable frequency on the generator include the possibility to operate the wind turbine at its maximum aerodynamic efficiency. The variable frequency also improves the power control by allowing the rotor of the wind turbine to act as a short-term storage that can absorb some of the power fluctuations as variations of the rotor speed. In order to investigate this wind turbine concept a joint project between Vestas, ABB and Risø was formed. The Danish Energy Agency supports the project. In this project both theoretical and experimental investigations have been undertaken eg through implementation of a test facility comprising a 225-kW wind turbine and a 400-kVA-frequency converter. The preliminary results show that indeed the power output is much smoother resulting in improved power quality and lower load on the gearbox. The project will continue to investigate different control strategies and their impact on power production and loads.

## 4.6 Test and measurements

The objective is to perform research based, internationally accredited testing of wind turbines, blades and other components in relation to type approval, documentation and support of the industrial development.

**Standards for measurements and testing (SMT), power quality task**

The purpose of this activity is to support the ongoing standardisation in IEC and Measnet on power quality for grid connection of wind turbines. Wind energy plays an increasing role in the power supply in many parts of the world. As a consequence, the influence of wind turbines on the power quality of the power transmission and distribution systems also increases. On this background the cooperation between wind turbine test stations, Measnet, has developed a draft procedure to measure wind turbine power quality characteristics. In January 1996 IEC TC88 appointed a working group, WG10, to produce a working draft of a standard "Power Quality Requirements for Grid Connected Wind Turbines".

The SMT project aims to specify and test procedures for measurement of power quality of wind turbines. The aim is also to specify and verify methods to normalise measurements from the influence of specific meteorological and grid conditions on a measurement site. Wind turbines are often connected to the power supply system as large wind farms. Therefore a specific task is also to specify methods to scale power quality characteristics of single wind turbines to wind farm power quality characteristics.

Four European test institutes participate in the project. Besides Risø, also DEWI (Germany), NEL (UK) and CRES (Greece) participate. To verify the existing test procedures, these four institutes have performed simultaneous measurements on a 600-kW Bonus wind turbine in complex terrain at wind farm Haghaw Hill in Scotland, and the results have been compared. Generally this activity showed good agreement between the results of the test institutions.

To specify the influence of the terrain on the power quality, measurements on a similar 600 kW Bonus are done in flat terrain at Gudum in Denmark. These measurements are now running, but comparison with the measurements in complex terrain has not been done so far.

The project also includes analysis of measurements on 500-kW Enercon variable speed wind turbines. Measurements on a strong grid Germany are now being compared to measurements on a much weaker grid on Gotland. It has been shown that existing voltage harmonics will cause the wind turbine to produce current harmonics of the same orders.

The project has provided specifications and tests of measurement procedures for IEC TC88 WG10, especially for flicker measurements and assessment.

## 4.7 Type approval and certification

The objective is to perform internationally accredited type approval of wind turbines and project certification of international wind-turbine projects based on research. The tasks are performed in commercial terms. Type approvals are carried out in an international co-operation with the classification society Norske Veritas.

In 1979 Risø was authorised by the Danish Energy Agency to approve wind turbines. Today the area of type approval is deregulated, and we offer type approvals and certification as a commercial service to the international wind-turbine industry. According to EN45011 Risø is accredited by DANAK, and our type approval and certification activities are organised in a separate organisational entity as prescribed by the accreditation authorities. For several years now we have had a co-operation with Det Norske Veritas (DNV) on type approval and certification on an international level.

Among our services is the "one-stop-stopping" type approval procedure where type approvals for several markets are issued in one process. This enables DNV and Risø to issue type approval certificates according to national rules in The Netherlands and Denmark and a "Gutachten" according to national rules in Germany. Recently we have been able also to offer certification of towers and concrete foundations in Germany. To be mentioned also is that among others the authorities in Greece, Norway, Sweden and India accept type approvals issued by DNV and Risø.

In order to carry out the type approval activities required Risø and DNV are qualified within the following areas.

- meteorology
- aerodynamics
- aeroelasticity
- probabilistic design
- material technology
- machinery
- structural design
- testing and measuring methods
- inspection methods
- quality systems

Type approval is recommended for wind turbines in serial production. Type approval is a verification of the wind-turbine design according to an approval scheme. This scheme may be extended to cover specific national requirements. Certification is applicable for individual wind turbines as well as for complete wind-turbine projects and their operation. A project certification may include verification activities during all stages of the project. A certificate issued for a complete project which has been found to comply with the agreed requirements. The certificate may be maintained during operation through periodic surveys and audits.

ISO 9000 is an internationally recognised quality system standard. ISO 9001 and ISO 9002 are relevant to wind turbine industry. ISO 9001 specifies the quality system requirements for design, development, production, installation and service. If design and development are not involved, then ISO 9001 is to be applied. It specifies the requirements for production, installation and service.

A world-wide certificate for quality assurance should be accredited ie approved on a national basis according to eg one of the schemes to which DNV is accredited, at present fourteen difference accreditation schemes.

## 4.8 Experimental meteorology

The objective is to perform research-based implementation of meteorological measurements to be used in boundary-layer experiments and long-term monitoring work. Some of the activity is carried out in connection with the departmental programme research and some for external clients. The work is carried out on programme-research or commercial terms dependent on the nature of the individual task.

### Summary of activities during 1997

EME activities are divided into three broad categories. One is development and maintenance of instruments and data systems. Another is operation of measuring stations. This means stations that are not dedicated to specific programs, but where long-term reliable climatology measurements are the key facet s. Last but not least participation in the experimental and monitoring parts of many of the projects undertaken by the other programs of the department. Many EME activities therefore are included in the description of experimental projects presented within the headings of the other programs of the department.

One aspect of these measuring campaigns could be emphasised. The year 1997 was the first year where the developed capability of on-site data analysis of larger field campaigns was successfully applied. This means that when an experiment is dismantled, all of the raw analysis has been conducted, and not only the measurements themselves.

Also 1997 was the first year where data from many of the measuring stations operated by EME were transmitted on the Web to facilitate data control of remote stations, but also simply to make the data available for co-operators and the public.

# 5 Co-operation and Dissemination

## 5.1 Partners and co-operation

Successful research utilisation is of paramount importance for the department. Stake holders (clients) and parties interested in our research can be divided into three categories:

- Industry
    - wind power industry
    - consultancy
    - power utilities
- Authorities
    - national (eg Danish Emergency Management Agency, Danish Environmental Protection Agency, Danish Energy Agency, DANIDA, Danish Veterinary and Food Administration)
    - European (eg EU, CEC, CEN/CENELEC)
    - international (eg WMO, IEA, IEC, UN, the World Bank)
- Scientific communities
    - universities and research laboratories (eg Danish Institute of Plant and Soil Science, AAU, DTU, KU, NCAR (USA), NREl (USA), ECN (The Netherlands), DEWI (Germany), CRES (Greece), CIEMAT (Spain), Karlsruhe Univeristy (Germany), EUREC-Agency)
    - PhD programmes

The department makes use of a number of channels to interact with these stake holders:

- direct dialogue
- direct co-operation on R&D projects under Danish and European R&D programmes
- international conferences
- international standardisation
- research based type approval activity
- research based turbine and blade testing activity
- publications
    - informal but fast (fax information to industry and other users
    - research reports (both public and internal/confidential)

- standards and guidelines
- conference contributions
- papers in peer reviewed journals

The department is involved in a number of research projects in co-operation with partners from industry and other private or semi-private enter-prises. Among these are A/S Wincon, ABB, Bonus Energy A/S, Carl Bro A/S, COWI A/S, Dahl Instruments, Dan Service A/S, Danish Standard, DEFU, Danish Slaughterhouses, Det Norske Veritas A/S, DMI, DMU, DTI, Elkraft, Elsam, EPP (Greece), Garrad & Hasan (UK), Genvind Production, Kampsax A/S, LM Glasfiber A/S, N.E.G. Micon A/S, MST, Great Belt Connection A/S, Svendborg Brakes A/S, Vestas Wind Systems A/S, WEA A/S, WindWorld of 1997.

**Direct dialogue with industry**

Before the 1997 round of submitting proposals to the Danish Energy Research Programme '98, the head of the department, the deputy head and the head of two of our research programmes paid a visit to a number of Danish wind turbine companies. The director of the Association of Danish Wind Turbine Manufacturers attended the visit. The purpose of the visit was to discuss future research projects and possibilities for co-operation. The team had discussions with the chief executives of the companies and heads of their R&D departments.

**Risø Wind Day '97**

This event took place on 14 August with approximately 100 participants. A broad range of Risø's wind energy activities was presented to an invited audience among our key stake holders.

### Theme conferences

In 1997 a theme conferences was held concerning Risø's activities within international standardisation on wind energy technology with focus on dissemination and dialogue with the industry and utility companies and their R&D departments.

## 5.2 Programme participation

Programme participation is the most significant contribution to the department's R&D turnover.

On a national level the department participates in the Energy Research Programme (EFP), Development Programme for Renewable Energy (UVE), Environmental Research Programme (SMP) and projects under the governmental technical research council (STVF). The total financial frame of these programmes (especially the research part) is increasing. For most contracts part of the funding is transferred via Risø to other partners, sub-contractors and consultants.

On a European level the department has had great success in obtaining contracts under a number of EU research programmes among which are JOULE, THERMIE, EUREKA, MAST, ENV, SMT and APAS. The department also participates in projects under Nordic Council's research programme.

On an international level (outside EU) no available research funding exists. International co-operation is co-ordinated through the wind energy R&D agreement of IEA, but funded through national programmes. In 1997 the department participated in an IEA organised Round Robin test of an American wind turbine. The department also participated in several workshops and expert meetings arranged under the IEA Wind Energy R&D Agreement.

## 5.3 International co-operation

### 5.3.1 IEA international wind-energy co-operation

IEA (International Energy Agency) is an organisation under OECD, the economic co-operation organisation of the industrialised countries. IEA was established in the seventies soon after the first oil crisis. Among its activities is co-operation on research and development, improved technology for fossil fuel, nuclear fusion, energy conservation as well as renewable energy. The IEA co-operation agreement on wind energy was started in 1977 and has existed now for 20 years.

The co-operation has concerned mainly research as eg international meetings of experts and "recommended practices" have been drawn up in a number of fields. To mutual benefit the individual member states have learned about the policies on wind energy in the other countries at execution committee meetings.

The wind-energy co-operation is joined by the following countries: Australia, Austria, Canada, Denmark, the European Commission, Finland, Germany, Greece, Italy, Japan, Mexico, The Netherlands, New Zealand, Norway, Spain, Sweden, UK and USA. India is presently observer at the meetings.

A change of the present focus of the co-operation activities is now being considered. This is because of the dramatic development in wind energy with respect to economics, technology and markets. It is desirable to involve the industry and utility companies in an even closer co-operation. It is a special wish by IEA for the IEA wind-energy agreement to play a role in connection with implementation of wind power in developing countries and in the countries of Eastern Europe. This will take place in a more or less formal co-operation with the World Bank.

Per Dannemand Andersen (the Test Station for Wind Turbines) is chairman of an international strategy group working on the future IEA wind-energy agreement. This work will be concluded in the beginning of 1998, and the new working plan for the IEA wind-energy agreement is to be finally agreed upon at a later date in 1998.

### 5.3.2 EUREC

Care for the environment and finite reserves of fossil fuels dictate that the world demand for energy will increasingly be met by renewable technologies. Since 1970 the clean and sustainable power from the sun, wind, waves, water and bio mass has been increasingly used to provide energy around the globe. Recent studies have shown that advanced renewable energy technologies have the potential to cover a substantial part of the primary energy consumption in the European Union and in the rest of the world in the next decades.

Within the European Union in general, increasing financial and technical support is being applied to develop our ability to exploit the enormous potential of renewable energies. This support has taken many forms including R&D funding, demonstration, commercialisation and technology transfer projects.

Together with a number of national renewable energy research centres the department founded the European Renewable Energy Centre in 1991. It was set up as a European Economic Interest Grouping to provide a forum for interdisciplinary co-operation. Today EUREC-Agency has 35 members. It includes the most respected renewable energy organisations in Europe, ranging from academic institutions and national research centres to other organisations responsible for major R&D programmes and projects for education, training and technology transfer activities. The objectives of EUREC-Agency are:

- to promote international collaboration within science, technology and education
- to advise the European Commission on scientific and technical policy and priorities in R&D programmes and to advise on and support political initiatives with the aim to increase the use of energy from renewable energy sources
- to assess realistic technical and economic goals to develop renewable energy technologies in the broadest perspective, taking social and environmental limitations into account
- to provide a platform for discussion and exchange of information with related organisations such as associations of utilities (EURE), associations of architects (READ) and international organisations such as UNDP, the World Bank and UNESCO
- to discuss collaboration between the EUREC members and industry
- to undertake technical co-operation with institutions in developing countries and emerging economies of Eastern and Central Europe including exchange of research staff, joint programmes in R&D and technology transfer.

These activities should lead to a better co-ordination and rationalisation of the efforts aiming at a further development of renewable energy technologies and their integration into the existing energy infrastructure.

### 5.3.3 MEASNET

The international measurement network MEASNET is an agency formed in 1997 as a European Renewable Energy Centres (EUREC-Agency) activity. The network was established by the present members, all of which are European wind energy institutions:

- CIEMAT (Spain)
- CRES (Greece)
- DEWI (Germany)
- ECN (The Netherlands)
- NEL (United Kingdom)
- RISØ (Denmark) and
- WINDTEST Germany).

The preparatory work and implementation have been performed in the framework of the European Wind Turbine Standards, EWTS-project and supported by the European Commission. To ensure high quality measurements, uniform interpretation of standards and recommendations as well as interchangeable results, the members established an organisational structure for MEASNET where mutual periodical quality procedures for measurements and evaluations are performed.

MEASNET members are independent of industry and accredited to EN45001 for the MEASNET approved measurements. The following recognised measurements can be performed under the MEASNET quality criteria:

- anemometer calibrations
- power performance
- power quality and
- noise.

All agreed measurement procedures take into account final or draft versions of international organisations, eg IEC, IEA and in addition results of project and measurement experiences.

### 5.3.4 EWEA

The aim of the European Wind Energy Association (EWEA) is to actively promote the maximum utilisation of wind power generation within the European Union and beyond. Among the means of EWEA is lobbying the EU for adequate research funding. An EWEA working group has been established to formulate suggestions for a European R&D strategy on wind energy technology. Peter Hjuler Jensen is a member of the board of EWEA and deputy chairman of the EWEA working group on technology and standardisation.

## 5.4 Committee and expert group memberships

Christensen, C.J., *Chairman,* International Electrotechnical Committee, Technical Committee 88, Wind Turbine Systems.

Christensen, C.J. Dansk Eletroteknisk Komite, DEK. Teknisk Udvalg (TU88) Sikkerhed af Elproducerende Vindmøller (Danish Electrotechnical Committee, Technical Committee TU88, Safety on Wind Turbine Generator Systems).

Christensen, C.J. International Electrotechnical Committee (IEC). Technical Committee 88 (TC88) Safety of Wind Turbine Generator Systems, Working Group 17.

Christensen, C.J. *Chairman*, European Standards for Wind Turbines, CENELEC BTTF 83-2.

Dannemand Andersen, P. Danish Energy Agency, Co-ordination Group on Wind Energy.

Dannemand Andersen, P. Danish Energy Agency, Technical Committee on Certification and Type Approval.

Dannemand Andersen, P. Danish Energy Agency, Advisory Committee on Certification and Type Approval.

Dannemand Andersen, P. International Energy Agency Implementing Agreement on Wind Energy (IEA R&D Wind), Executive Committee.

Dannemand Andersen, P. *Chairman,* International Energy Agency Implementing Agreement on Wind Energy (IEA R&D Wind), Strategy Committee.

Frandsen, S. Steering Committee for the Egyptian-Danish Collaboration Project on Wind Energy.

Frandsen, S. Dansk Elektroteknisk Komite, DEK. Teknisk Udvalg (TU88) Sikkerhed af Elproducerende Vindmøller (Danish Electrotechnical Committee, Technical Committee TU88, Safety on Wind Turbine Generator Systems).

Frandsen, S. International Electrotechnical Committee (IEC), Technical Committee TC88, Working Group 6, Test Procedures for Wind Turbine Testing.

Gryning, S.E. *Deputy Chairman*, Danish Meteorological Society (DAMS).

Gryning, S.E. *Honourable Secretary*, European Association for the Science of Air Pollution (EURASAP).

Gryning, S.E. *Chairman*, Executive Committee, NOPEX.

Gryning, S.E. International Scientific Committee on the 5th international conference on harmonisation within atmosphere dispersion modelling for regulatory purposes.

Gryning, S.E. *Chairman*, Scientific Steering Committee on NATO/CCMS International Technical Meetings on Air Pollution Modelling and Its Application, Conference Series.

Gryning, S.E. COST Action 710. Processing of Meteorological Data for Dispersion Modelling. Working Group 2: Mixing-Layer Depth Determination for Dispersion Modelling.

Gryning, S.E. Science Panel on Atmospheric Chemistry Research (DG XII, EU).

Gryning, S.E. International Scientific Committee on the ETEX (European Tracer Experiment) Symposium, Vienna, May 1997.

Gryning, S.E. International Scientific Committee on the Stable Boundary Layer Workshop, Sweden, October 1997.

Gryning, S.E. International Scientific Committee on Operational short-range atmosphere Dispersion Models for Environmental Impact Studies. Workshop Series.

Gryning, S.E. *Chairman*, EURASAP Workshop on the Determination of the Mixing Height - Current Progress and Problems, Risø National Laboratory, 1-3 October 1997.

Gryning, S.E. *Guest Editor*, Atmospheric Environment, Special Issue of the MEDCAPHOT Trace Experiment.

Gryning, S.E. *Guest Editor*, Journal of Agriculture and Forest Meteorology. Special issue of the NOPEX experiment.

Harvøe, P. Danish Energy Agency. Technical Committee for Small Wind Turbines.

Harvøe, P. Danish Energy Agency. Promoter Committee for Small Wind Turbines.

Harvøe, P. Tønder Technical School, Educational Wind Farm.

Hasager, C.B. DANMAC, Danish Multisensor Airborne Campaign.

Hasager, C.B. Corps of External Examiners, University of Copenhagen.

Hummelshøj. P. *Secretary*, Nordic Society for Aerosol Research (NOSA).

Hummelshøj, P. International Advisory Organisation Committee, The Aerosol Society.

Højholdt, P. Danish Energy Agency, Promoter Committee for Small Wind Turbines.

Højholdt, P. Technical Committee for Domestic Wind Turbines.

Jensen, N.O. European Geophysical Society. *Secretary of Meteorology* under Oceans and Atmosphere (OA).

Jensen, N.O. *Secretary*, Steering Committee, Danish Centre for Atmospheric Research (DCAR).

Jensen, N.O. National Committee of IUTAM (International Union of Theoretical and Applied Mechanics).

Jensen, N.O. National Committee for the International Geosphere-Biosphere Programme (IGBP).

Jensen, N.O. *Editorial Board*, Boundary-Layer Meteorology.

Jensen, N.O. *Chairman*, Boundary Layer Dynamics and Air-Sea Interaction. Working Group A, under ICDM/IAMAS (International Commission on Dynamic Meteorology/International Association of Meteorology and Atmospheric Physics).

Jensen, N.O. *Secretary*, International Commission of Dynamic Meteorology (ICDM).

Jensen, N.O. *Associate Editor*, Quarterly Journal of Royal Meteorological Society.

Jensen, N.O. Expert Group Geoscience, Swedish Natural Science Research Council.

Jensen, P.H. International Electrotechnical Committee (IEC). Technical Committee 88 (TU88), Safety of Wind Turbine Generator Systems, Working Group 17.

Jensen, P.H. Dansk Elektroteknisk Komite, DEK. Teknisk Udvalg 88 (TU 88) Sikkerhed af Elproducerende Vindmøler (Danish Electrotechnical Committee, Technical Committee TU 88 Safety on Wind Turbine Generator Systems).

Jensen, P.H. *Chairman*, Danish Energy Agency, Committee on Criteria for Design and Certification of Wind Turbines, Working Group 17: Operation and Maintenance.

Jensen, P.H. Danish Energy Agency. Technical Committee on Criteria for Design and Certification of Wind Turbines. Working Group on Control and Safety Systems for Wind Turbines.

Jensen, P.H. *Convenor*, International Electrotechnical Committee (IEC), Technical Committee 88 (TC 88) Safety on Wind Turbine Generator Systems.

Jensen, P.H. *Secretary*, European Wind Energy Association (EWEA), Corporate Group.

Jensen, P.H. Danish Energy Agency. Wind Energy Advisory Committee.

Jensen, P.H. Danish Energy Agency, Wind Energy Research Committee (DK).

Jensen, P.H. European Standards for Wind Turbines, CENELEC BTTF 83-2.

Jensen, P.H. European Wind Energy Association (EWEA). Corporate Group.

Kristensen, L. *Associate Editor*, Quarterly Journal of Royal Meteorological Society.

Krogsgaard, J. *Governing Board*, European Small Hydro Power Association (ESHA).

Krogsgaard, J. *Editorial Board*, Atlas of European Small-Scale Hydro Power Potential (ESHA).

Krogsgaard, J. European Small Hydro Power Association (ESHA).

Krogsgaard, J. *Editorial Committee*, European Small Hydro Power Association (ESHA). Layman's Guidebook on how to develop a small Hydro site (ESHA).

Krogsgaard, J. *Editorial Board*, JWB study on Hydro power.

Larsen, S.E. National Committee for the International Geosphere-Biosphere Programme (IGBP).

Larsen, S.E. Co-ordination Committee on the Marine Aerosol and Gas Exchange Project of the International Global Atmospheric Chemistry Program.

Larsen, S.E. National Committee for Climate Research. Danish Committee under the World Climate Programme.

Larsen, S.E. Scientific Committee on Ocean Research (SCOR), Working Group 101 on Influence of Sea State on the Atmospheric Drag Coefficient.

Larsen, S.E. Steering Committee for the Test and Accreditation Secretariat for Wind Turbines at Risø National Laboratory.

Larsen, S.E. Scientific Committee of EUROTRAC2.

Larsen, S.E. Steering Committee, EUROTRAC2-CAPP Project .

Madsen, P.H. *Chairman,* Dansk Standard (DS). Teknisk Udvalg S588, Sikkerhed af Elproducerende Vindmøller (Danish Standard, Technical Committee S588, Safety of Wind Turbine Generator Systems).

Madsen, P.H. *Chairman,* International Electrotechnical Committee, Technical Committee 88 (TC 88), Safety of Wind Turbine Generator Systems, Working Group 7, Revision of Part 1: Safety Requirements.

Madsen, P.H. *Chairman,* International Electrotechnical Committee (IEC). Technical Committee 88 (TC88), Safety of Wind Turbine Generator Systems, Working Group 9: Certification Procedures of Wind Turbines.

Madsen, P.H. International Electrotechnical Committee (IEC).Technical Committee 88 (TC88).

Madsen, P.H. European Standards for Wind Turbines, CENELEC BTTF 83-2.

Madsen, P.H. *Board Member,* Fuel and Combustion Technology Association, Danish Society of Chemical, Civil, Electrical and Mechanical Engineering (IDA).

Madsen, P.H. *Editorial Board,* "Wind Energy", Wiley & Sons.

Mikkelsen, T., RODOS Management Group on Radiation Protection Research (RMG), EU, DG-XII, Nuclear Safety.

Mikkelsen, T. *Working Group Leader* for Atmospheric Dispersion within the RODOS real-time Decision Support System, EU, DG-XI/&XII.

Mikkelsen, T. International Scientific Committee on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes.

Mikkelsen, T. *Co-ordinator,* EU Concerted Action Program on Real-time Models for Intercomparison (RTMOD).

Mikkelsen, T. *Chairman,* SMP workshop on the stochastic nature of smoke plumes, Risø National Laboratory (DK), 4 Feb 1997.

Mortensen, N.G. Nordic TeX Committee.

Mortensen, N.G. Quality Control Committee on Exhibition on Energy Production and Environment.

Mortensen, N.G. Corps of External Examiners, University of Copenhagen.

Pedersen, T.F. Dansk Elektroteknisk Komite, DEK. Teknisk Udvalg 88 (TU88), Sikkerhed af Elproducerende Vindmøler (Danish Electrotechnical Committee, Technical Committee TU88, Safety on Wind Turbine Generator Systems).

Pedersen, T.F. *Chairman,* International Electrotechnical Committee (IEC), Technical Committee TC88, Working Group 6: Test Procedures for Wind Turbine Testing.

Pedersen, T.F. Danish Energy Agency, Technical Committee (IEC), Technical Committee on Certification and Type Approval.

Pedersen, T.F. *Convenor,* International Electrotechnical Committee (IEC), Technical Committee 88 (TC88) Power Performance Measurement Procedures.

Petersen, E.L. EUREC-Agency EEIG.

Petersen, E.L. *Editorial Board,* International Journal of Solar Energy.

Petersen, E.L. *Editor,* "Wind Energy", Wiley & Sons.

Petersen, E.L. *Chairman,* 1999 European Union Wind Energy Conference and Exhibition, 1 - 5 March 1999, Nice, France.

Rasmussen, F. *Editorial Board,* "Wind Energy", Wiley & Sons.

Skamris, C. International Electrotechnical Committee (IEC), Technical Committee TC88, Working Group 9: Certification Procedures of Wind Turbines.

Skamris, C. Danish Energy Agency, Technical Committee (IEC), Technical Committee on Certification and Type Approval.

Søndergaard, L. *Editorial Board,* "Wind Energy", Wiley & Sons.

Sørensen, P. International Electrotechnical Committee (IEC), Technical Committee TC88, Working Group 10.

Tande, J.O. *Chairman*, International Electrotechnical Committee (IEC), Technical Committee TC88, Working Group 10.

Tande, J. *Editorial Board*, "Wind Energy", Wiley & Sons.

Thykier-Nielsen, S. Ad Hoc Group on the NEA/CEC Intercomparison Exercise on PCA Codes.

Winther-Jensen, M. Advisory Committee on Insurance, The Danish Wind Power Utilities.

Winther-Jensen, M. Transmission Technical Advisory Committee (GIG).

Winther-Jensen, M. International Electrotechnical Committee (IEC). Technical Committee 88 (TC88), Working Group 8, Testing of Rotor Blades.

Winther-Jensen, M. European Standards for Wind Turbines, CENELEC BTTF 83-2.

Winther-Jensen, M. Danish Energy Agency. Technical Committee on Criteria for Design and Certification of Wind Turbines. Working Group on Blades.

Winther-Jensen, M. Danish Energy Agency. Technical Committee on Criteria for Design and Certification of Wind Turbines. Working Group on Quality Management.

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## 6.1 International publications

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## 6.7 Educational activities

Landberg, L.; Mortensen, N.G.; Rathmann, O., Two-day course in WASP: the wind analysis and application program. Risø National Laboratory, Ros-kilde (DK), 11-12 Sep. 1997

Larsen, S.E., Micro-scale meteorology. Course at NBIfAFG for graduate students, 50 lectures in the fall semester of 1997, oral examination

Larsen, S.E., Fluxes of $CO_2$ across the air-sea boundary. Lecture at a PhD course, Rødkilde Højskole, Stevns, Stege (DK), 3-7 Nov 1997

Thykier-Nielsen, S., Application of the RIMPUFF module of ARGOS-NT decision support system. ARGOS-NT training seminar, Tallinn, Estonia (EW), 9-12 Jun 1997

Thykier-Nielsen, S., Application of the RIMPUFF module of ARGOS-NT decision support system. ARGOS-NT training seminar, Riga, Latvia (LV), 16-19 June 1997

Thykier-Nielsen, S. The RIMPUFF module of ARGOS-NT decision support system: theoretical background and application. ARGOS-NT course, Helsingør (DK), 3-14 Nov 1997

## 6.8 Seminars held in the department

Ayotte, Keith "Optimisation of mean flow upstream boundary conditions in limited area modelling", August.

Barthelmie, Beki "An atmospheric stability atlas for Denmark?", August.

Bergmann, Juan "Momentum balance of PBL - physical and methodical problems, solutions", June.

Bruin, Henk de "On the use of scintillometers to measure surface heat and momentum fluxes", April.

Galmarini, S. "Modelling the turbulent transport of nitrogen oxides in the atmospheric boundary layer", September.

Hansen, S.O. "Danish and European wind load codes", May.

Horvath, Laszlo "Flux measurement of gases above pine forest by the gradient method in Hungary", February.

Jacobs, Cor M.J. "Air-sea flux and transfer velocity of $CO_2$", November

Lange, Bernhard "WASP for offshore sites - influence of the sea fetch", August.

Norris, David "Analysis of the complex acoustic signal for use in identifying outdoor propagation modes and effects of turbulence", April.

Sun, Jielun "Ozone transport in California ozone deposition experiment" and "Transport of carbon dioxide, water vapour and ozone by land/lake breezes", October.

Tillman, Jim "Enhanced mode lidar planetary wind sensor for Earth and Mars", October.
Tillman, Jim "Temperature based estimation of PBL parameters in the unstable atmosphere", November
Verkaik, Job "Momentum flux and wind profile measurements over heterogeneous terrain", April.
Vila-Guerau de Arellano, Jordi "Control of chemical reactions by convective turbulence in the boundary layer", February.
Wilson, David "Dispersion around buildings", February.

# 7 Staff and Guests

**Administration**
*Madsen, Peter Hauge, Deputy Department Head*
*Petersen, Erik Lundtang, Department Head*
**Secretaries**
Christiansen, Ulla Riis
Viktorius, Gitte

**Programme: Wind Turbines**
**Scientific staff**
Andersen, Per Dannemand
Christensen, Carl Jørgen
Frandsen, Sten Tronæs
Hansen, Jens Carsten
Harvøe, Per
*Jensen, Peter Hjuler, Programme Head*
Nørgaard, Per (on leave)
Winther-Jensen, Martin
**PhD and Post.Doc students**
Hansen, Lars Henrik (from 15 Sep 1997)
**Technical staff**
Hagensen, Flemming
**Secretaries**
Andersen, Mette Kuhlmann
Henriksen, Mette Porsdal (on leave)
Westermann, Kirsten

**Programme: Aerodynamic Design**
**Scientific staff**
Fuglsang, Peter
Larsen, Gunner
Madsen, Helge Aagaard
Petersen, Jørgen Thirstrup
*Flemming Rasmussen, Programme Head*
Sørensen, Niels Nørmark
Thomsen, Kenneth
Vølund, Per
**PhD and Post.Doc students**
Bak, Christian (from 1 Feb 1997)
Bertagnolio, Franck (from 1 Sep 1997)
Dahl, Kristian Skriver
Johansen, Jeppe
**Secretary**
Westermann, Kirsten

**Programme: Electric Design and Control**
**Scientific staff:**
Bindner, Henrik W.
*Hjuler Jensen, Peter, Programme Head*
Sørensen, Poul
Tande, John (till 31 May 1997)
**PhD and Post.Doc students**
Søndergaard, Lars
**Secretary**
Madsen, Jytte

**Programme: Wind Power Meteorology**
**Scientific staff**
Frank, Helmut
Højstrup, Jørgen
Kristensen, Leif
*Landberg, Lars, Programme Head*
Mann, Jakob
Mortensen, Niels Gylling
Rathmann, Ole
PhD and post.doc students
Giebel, Gregor
Joensen, Alfred
Larsen, Lisbeth (from 1 August)
Sempreviva, Anna Maria
**Secretary**
Skrumsager, Birthe

**Programme: Wind Energy and Atmospheric Processes**
**Scientific staff**
Astrup, Poul
Gryning, Sven Erik
Hummelshøj, Poul
Jensen, Niels Otto
Jørgensen, Hans
*Larsen, Søren, Programme Head*
Mikkelsen, Torben
Nielsen, Morten
Thykier-Nielsen, Søren
**PhD and post.doc students**
Bergmann, Juan (from 1 April)
Falk, Anne Katrine Vinther
Geernaert, Lise Lotte Sørensen
Hasager, Charlotte Bay
Helin, Astrid (from 1 September)
Kjeld, Jørgen Friis
Vignati, Elisabetta
**Secretary**
Skrumsager, Birthe

**Special Task: Tests and Measurements**

**Scientific staff**

Antoniou, Ioannis
Fischer-Nielsen, Thomas
Grove-Nielsen, Erik (Sparkær)
Krogsgaard, Jørgen
Lind, Søren Ømann
Paulsen, Uwe Schmidt
*Pedersen, Troels Friis, Head*
Petersen, Søren Markkilde

**Technical staff**

Christensen, Kurt
Hansen, Per
Hansen, Stener
Høst, Oluf
Lund-Thomsen, Hans (Sparkær)
Nielsen, Finn Linke
Rasmussen, Michael

**Secretary**

Hansen, Anne-Marie

**Special Task: Type Approval**

**Scientific staff**

Højholdt, Poul
Jørgensen, Erik Rosenfeldt
Kock, Carsten Weber
*Skamris, Carsten, Head*

**Technical staff**

Lange, Rolf

**Secretary**

Hansen, Anne Marie

**Special Task: Experimental Meteorology**

**Scientific staff**

Courtney, Mike
*Larsen, Søren, Head*
Sanderhoff, Peter

**Technical staff**

Christensen, Lars
Hansen, Arent
Hansen, Finn
Hansen, John
Jensen, Gunnar
Lund, Søren
Nielsen, Jan

**Secretary**

Skrumsager, Birthe

## 7.1 Guest scientists

| | | |
|---|---|---|
| Barthelmie, Rebecca | 07.04 - 16.08 | Univ. of Indiana, USA |
| Batchvarova, Ekaterina | 05.03 - 16.12 | Nat. Inst.. of Meteorology and Hydrology, Sofia, Bulgaria |
| Borodin, Ruslan | 19.04 - 16.05 | USSR Committee for Hydrometeorology, Obninsk, Russia |
| Chen, Zhong | 01.01 - 31.08 | University of Beijing, China |
| Coppin, Peter | 08.10 - 17.10 | CSIRO, Canberra, Australia |
| Goodwill, Gilbert | 25.05 - 25.06 | Kamada Science & Design, Monterey, CA, USA |
| Kunz, Gerard | 13.11 - 27.11 | TNO, The Netherlands |
| Lange, Bernhard | 01.03- 31.08 | University of Oldenburg, Germany |
| Molnary, Leslie de | 28.03 - 04.07 | IPEN-CNEN/SP, Sao Paulo, Brazil |
| Moreno, Josep | 25.08 - 19.12 | Barcelona, Spain |
| Parnis, Paul | 01.01 - 31.08 | Australia |
| Pryor, Sara | 10.07 - 16.08 | Indiana University, Bloomington, USA |
| Reis, Miguel | 07.08 - 15.08 | Univ. of Lisboa, Portugal |
| Sun, Jielun | 12.08 - 18.10 | Univ. of Colorado, Boulder, CO, USA |
| Tillman, Jim | 13.10 - 12.11 | Univ. of Washington, Seattle, WA, USA |
| Weber, Harald | 21.09 - 01.10 | German Military Geophysics Office, Traben-Trarbach, Germany |
| Zhanrong, Gao | 14.02 - 17.04 | People's Republic of China |

## 7.2 Short-term visitors (one week or less)

| | | |
|---|---|---|
| Ayotte, Keith | 19.08 - 25.08 | CSIRO, Canberra, Australia |
| Bozo, Laszlo | 17.02 - 21.02 | Institue for Atmospheric Physics, Budapest, Hungary |
| Bradley, Frank | 07.05 - 11.05 | CSIRO, Canberra, Australia |
| Bruin, Henk, de | 07.04 - 10.04 | Wageningen Agricultural University, The Netherlands |
| Galmarini, S. | 01.10 - 03.10 | Ispra, Italy |
| Cionco, Ronald | 21.09 - 27.09 | ARL, Washington D.C., USA |
| Hee, Han Moon | 22.11 - 28.11 | KAERI, Korea |
| Horvath, Laszlo | 17.02 - 21.02 | Institute for Atmospheric Physics, Budapest, Hungary |
| Jacobs, Cor M. | 24.11 - 26.11 | KNMI, The Netherlands |
| Kamada, Ray | 13.08 - 15.08 | Kamada Science & Design, Monterey, USA |
| Kulkarni, V.P. | 25.09 - 27.09 | Government of India, Thiruvananthapuram, India |
| Lavagnini, Alfredo | 09.12 - 13.12 | Istituto di Fisica dell'Atmosfera, Rome, Italy |
| Lee, J.H. | 22.11 - 26.11 | KAERI, Korea |
| Mahrt, Larry | 18.08 - 22.08<br>13.10 - 15.10 | Oregon State University, Corvallis, USA |
| Martens, Reinhard | 24.11 - 26.11 | GRS, Köln, Germany |
| Moon, Hee Han | 22.11 - 28.11 | KAERI, Korea |
| Nedoma, Petr | 01.06 - 15.06 | Academy of the Czech Republic, Praha, The Czech Republic |
| Noreland, Jakob | 20.02 - 21.02 | FOA, Umeå, Sweden |
| Norris, David | 13.04 - 18.04 | Penn State University, USA |
| Sagi, Laszlo | 14.04 - 18.04 | KFKI, Budapest, Hungary |
| Sokolskii, A. | 20.10 - 24.10 | VIESH, Russia |
| Starkov, Alexander | 01.09 - 06.09 | RDIEE, Istra, Moscow, Russia |
| Sugimoto, Shin | 16.10 - 19.10 | Japan |
| Verkaik, Job | 07.04 - 10.04 | Wageningen Agricultural University, The Netherlands |
| Vickers, Dean | 22.09 - 29.09 | Oregon State University, Corvallis, USA |
| Wilson, David | 03.02 - 06.02 | University of Albana, Edmonton, Canada |
| Zita, Ferenczy | 14.04 - 18.04 | National Meteorological Institute, Budapest, Hungary |

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Abstract (max. 2000 characters)

The report describes the work of the Wind Energy and Atmospheric Physics Department at Risø National Laboratory during 1997. The research of the department aims to develop new opportunities in the exploitation of wind energy and to map and alleviate atmospheric aspects of environmental problems. The expertise of the department is utilised in commercial activities such as wind turbine testing and certification, training programmes, courses and consultancy services to industry, authorities and Danish and international organisations on wind energy and atmospheric environmental impact.

A summary of the department's activities in 1997 is presented, including lists of publications, lectures, committees and staff members.

Descriptors INIS/EDB

AIR POLLUTION; BOUNDARY LAYERS; METEOROLOGY; PROGRESS REPORT; RESEARCH PROGRAMMES; RISOE NATIONAL LABORATORY; WIND TURBINES

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